1992

Dolores River Basin Water Quality Study

Department of Interior; Bureau of Reclamation, Technical Service Center; Denver, CO

DOLORES RIVER BASIN

WATER QUALITY STUDY

Prepared by

United States Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado
and
Durango Projects Office
Durango, Colorado

MISSION STATEMENTS

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

The mission ... develop, and protect wate... ientally and economically ... public.

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Chapter I
BACKGROUND

PROBLEM

In 1988, Advance Planning Studies were conducted for the construction of Dawson Draw Reservoir, a fish and wildlife enhancement feature of the Dolores Project. These studies included evaluation of the soils, water supply, and biota in the Dawson Draw area with respect to heavy metals. The source of water supply for Dawson Draw Reservoir would have been the Dolores River, the same source of supply as Narraguinnep, Totten, and McPhee Reservoirs. These studies revealed elevated mercury (Hg) concentrations in selected species of larger fish in all the reservoirs. As a result, Narraguinnep, Totten, and McPhee Reservoirs have been posted by the Colorado Department of Health, warning the public of the hazards of human consumption of selected fish species.

PREVIOUS STUDIES

Pollution of the upper Dolores River has been documented as early as 1956 and probably occurred much earlier. A report entitled "Water Pollution Studies" by the Colorado Game, Fish and Parks Department, October 1966, documents pollution associated with mining activities in the Rico/Silver Creek area. The study identified two predominant sources of pollution, the Rico Mill located on Silver Creek and the St. Louis Tunnel, located just upstream of Rico adjacent to the Dolores River. This report offers the following observations:

> *The tailings from the Rico mill are located on the north side of the Silver Creek Valley. These are poorly maintained. There is good evidence that the mill periodically allows its tailings to run directly into Silver Creek. Silver Creek is now a grayish color with a gray precipitate on the rocks, heavy siltation, and there is usually foam on the surface of the water. The effluent from the tailings pond contains iron, manganese, copper, and zinc. There is also high concentrations of cyanides which exist as free CN and as heavy metal complexes.*
>
> *The pollution from the St. Louis Tunnel now consists of mine water drainage. This drainage runs through a series of tailing ponds where a portion of the iron and sulfate are removed from the mine water. The ponds drain directly into the Dolores River. This effluent contains iron, manganese and zinc at fairly high levels.*
>
> *The Dolores below the St. Louis Tunnel is a faint brown color. The rocks are heavily stained with precipitated iron, there is only moderate to light siltation. Bottom organisms are not plentiful.*

A report prepared by the Colorado Division of Wildlife entitled "Fish and Wildlife Analysis for the Dolores Water Project 1973-74" indicates that during the 1960's, mining and sulfuric acid production activities in the Rico area adversely impacted aquatic life as far downstream as to the confluence with the West Dolores River, approximately 20 miles.

During the planning phase of the Dolores Project, the Bureau of Reclamation (Reclamation) utilized all available historic water quality data and collected additional water quality samples in the preparation of the definite plan report and final environmental statement. Of the four samples collected from the river near the town of Dolores, one contained mercury concentrations of 0.5 microgram per liter (µg/L), the laboratory detection limit at that time. The drinking water and aquatic life standards were 2 µg/L and 0.05 µg/L, respectively. The drinking water standard has not changed. The aquatic life standard is still 0.05 µg/L in the Dolores Basin upstream from the mouth of Bear Creek, but it is now 0.01 µg/L in the mainstem downstream from that point. The single violation of the aquatic life standard was noted in both the draft and final environmental statements. At that time, there were no public health advisories for mercury contamination in the project area, and it appeared that mercury present in the water was not biologically available.

The Environmental Protection Agency (EPA) offered the following comments to the draft environmental statement:

> *The Bureau of Reclamation has described the nature of the heavy metal toxicity problems at the dam site. It does not appear likely that a significant problem with toxic substances would occur as a result of this project. There are, however, certain factors which could influence the solubility of the heavy metals, although, in this case, it appears unlikely that such factors would significantly alter the water quality of the reservoir. These factors include:*
>
> *a. Organic decomposition in the benthic layer of the reservoir could cause acidic conditions which would facilitate the dissolution of heavy metals.*
>
> *b. If significant amounts of heavy metal sulfates were on the bottom, sulfate bacteria could react with these salts and release the heavy metals back into solution.*
>
> *c. Turnover of the reservoir twice yearly could resuspend bottom sediments and mix any dissolved heavy metals resulting from the above two processes back into the water column.*

During the permitting process for Section 404 of the Clean Water Act, the Environmental Protection Agency requested that further monitoring be required. Special condition (b) of the permit states:

> *A Water Quality Monitoring Program shall be established by the Bureau of Reclamation in consultation with the Environmental Protection Agency prior to commencement of work and continue through all phases of the construction.*

A monitoring program was established and is continuing.

In an effort to further define the potential for water quality problems in the reservoir, Reclamation contracted with the Utah Water Research Laboratory for additional research of heavy metal toxicity and the potential for eutrophication in Colorado streams. Bioalgal assays were conducted in an effort to determine if these sources would reach toxic levels in the water or become biologically available. In June 1979, the "Pre-Impoundment Water Quality Study for the Dolores Project" was published by the Utah Water Research Laboratory (UWRL) and submitted to the Environmental Protection Agency. Following are excerpts from the report:

> *The water from the Dolores River exceeded the proposed agricultural use standard for total cadmium during 3 of 16 sampling rounds and for total cyanide, total copper and total manganese once each (table 16). However, the sampling periods in which these constituents exceeded the proposed standards were in the spring and fall, not during the irrigation season. During the summer months (June through September) none of the proposed standards for agricultural use were exceeded. The salinity of the Dolores River was very low and should pose no hazard to irrigated crops.*
>
> *The proposed Colorado Water Quality Standards for the protection of aquatic biota were exceeded by numerous metals during this study. The proposed standards for dissolved aluminum, total cyanide, total copper, total mercury, and total zinc were exceeded during at least half of the sampling periods (table 6). The standards for several other metals (total cadmium, total iron, total lead, total manganese, and total silver) were exceeded during one or more sampling periods. Algal bioassays were conducted at UWRL on waters from the Dolores River during September, 1977, November 1977, January 1978, March, 1978, and May, 1978 using the Algal Assay Procedure: Bottle Test (EPA, 1971). None of these bioassays indicated that the growth of S. capricornutum was suppressed by metal toxicity in water from the Dolores River at Dolores. However, during the September, 1977 bioassay testing, samples were included from other sites along the Dolores River. In these bioassays the growth of S. capricornutum was suppressed as the result of metal toxicity in the sample obtained from the Dolores River immediately above the tailing piles at Rico, Colorado.*

In 1988, Reclamation conducted a toxic trace element investigation as part of the design data collection program for construction of Dawson Draw Reservoir. This investigation included water, soil, and biota sampling in the proposed reservoir area. Analysis of the soil samples did not indicate a potential problem. Both mercury and selenium were detected at slightly elevated levels in some water samples. Biota samples included algae, macroinvertebrates, crayfish, fathead minnows, speckled dace, bullhead suckers, mallard ducks, and Canada geese. In laboratory tests, fathead minnows have been shown to have one of the highest bioconcentration factors for methylmercury of all fish tested; 81,670 times water concentration. Crayfish reproduction is very sensitive to elevated mercury concentrations, and crayfish are abundant in the proposed reservoir area. None of the biota samples from the proposed reservoir area contained toxic trace elements at problem levels.

As a part of this study, fish were sampled from McPhee, Narraquinnep, and Totten Reservoirs and from the Dolores River downstream from McPhee Dam. Larger fish from both McPhee and Narraquinnep Reservoirs contained elevated levels of mercury, while fish from the Dolores River and Totten Reservoir contained normal levels of trace elements. However, species of fish sampled from Totten did not include the species which contained elevated levels of mercury in the other reservoirs, and additional fish sampling was conducted. The following table shows the amount of mercury found in fillet samples from selected fish in McPhee, Narraguinnep, and Totten Reservoirs and the Dolores River downstream from McPhee Dam. The table also shows the amount of mercury which would be contained in 1 pound (lb) of each sample and the recommended weekly human intake limit for each sample.

Sample location	Fillet sample	Concentration of Hg (wet weight)	Mercury in 1 lb of fish fillet	Recommended weekly limit of fillet consumption by a 155-lb human
Narraguinnep	Walleye	1.37 µg/g[1]	621.42 µg[2]	5.15 oz
Narraguinnep	Walleye	1.26 µg/g	571.52 µg	5.60 oz
Narraguinnep	Northern Pike	0.99 µg/g	449.05 µg	7.13 oz
McPhee	Largemouth Bass	0.57 µg/g	258.55 µg	12.38 oz
McPhee	Rainbow Trout	0.32 µg/g	145.15 µg	21.89 oz
Dolores River	Brown Trout	0.075 µg/g	34.02 µg	94.06 oz

[1] µg/g = microgram per gram (equal to parts per million).
[2] µg = microgram.

The recommended limits of human mercury intake as listed by Eisler (1987) are:

1. No more than 250 micrograms (µg) for a pregnant female during entire gestation period.

2. No more than 25 µg/day or 200 µg/week for an indefinite period of time for a 155-lb human.

As a result of this study, the Colorado Division of Wildlife has posted both Narraguinnep and McPhee Reservoirs warning the public of the hazard of human consumption of selected fish species.

Chapter II
LOCATION AND STUDY SETTING

DESCRIPTION OF THE STUDY AREA

The study area includes the Dolores River basin from just above Barlow Creek on the mainstem and from just above Cold Creek on the West Dolores River to the United States Geological Survey (USGS) stream gauging station, Dolores River at Dolores, Colorado. Most of the major tributaries and Lost Canyon, which enters the Dolores River just below the town of Dolores, were also included. The higher reaches of the Dolores and West Dolores Rivers were not included due to the difficulty of access.

The headwaters of the river are located on the south slopes of the San Juan Mountains and the west slopes of the La Plata Mountains. Several peaks along the divide with the San Miguel River (San Juan Mountains) are over 14,000 feet in elevation. The peaks along the divide with the Animas, La Plata, and Mancos Rivers reach elevations of over 13,000 feet. The higher elevations of the upper basin are characterized by bare rocky peaks, steep rocky slopes, and narrow canyons. Timberline elevation averages about 11,000 feet. Below timberline, spruce and aspen forest, meadows, and small shrubbery characterize the upper basin. The south and west divides are plateaus varying in elevation from about 7100 to 10,000 feet. These portions of the basin are characterized by pine forest and meadows at the higher elevations and pinion, juniper, oak, sage, and miscellaneous brushes at the lower elevations.

HYDROLOGY

Annual precipitation varies from approximately 18 inches at the town of Dolores to over 50 inches at the headwaters. Approximately 50 to 60 percent of the precipitation falls as snow. The total drainage area of the Dolores River basin above the United States Geological Survey gauging station at the town of Dolores is 504 square miles. The average annual yield of the basin at this point is 316,200 acre-feet. Lost Canyon, which enters the Dolores River below the gauging station at Dolores, has a drainage area of about 71 square miles and an average annual yield of about 18,970 acre-feet. Much of the water from the Lost Canyon basin is diverted from near the headwaters into the San Juan basin for irrigation use.

GEOLOGY

Regionally, the soil and water quality study area is located in the east-central portion of the Colorado Plateau physiographic province. This plateau is a high structural platform consisting of Precambrian basement igneous and metamorphic rock, a moderately thick sedimentary sequence of marine and continental sandstone, shale, mudstone, and evaporites ranging from Cambrian to Cretaceous in age. Igneous rocks of Tertiary and Tertiary/Cretaceous age are located near the Dolores River. Quaternary age unconsolidated sediments are also found within the Colorado Plateau.

Three major tectonic units border southwestern Colorado. The Four Corners Platform is located to the south, the Paradox Fold and Fault Belt to the north, and the San Juan Dome to the east of the project area.

Several tectonic episodes have influenced the structural framework of the region including the Uncompahgre Uplift to the northeast, the rising and subsequent collapse of salt anticlines in the Paradox Belt, the House Creek Fault, and general movement associated with the San Juan Dome.

The topography of the area ranges from deeply incised river and stream canyons which are tributaries to the Colorado and San Juan Rivers to areas of low relief. The area also consists of isolated buttes and mesas in the lowland areas with rugged mountain topography in the headwater areas.

The following geologic units are located within the project area:

Alluvial Deposits (Qal): Silt, sand, and gravel in stream valleys and flood plains. These deposits may also include some soil and localized colluvium deposits.

Intrusive Igneous Rocks (Ti): Sills, dikes, and small plutons; mostly calcic granodiorite, but may include lamprophyre and rhyolite. Occurs mainly in the West Dolores River area near Black Mesa. These intrusives may be responsible for elevated Hg and trace metal levels in this localized drainage area.

Monchiquite (Tmq): Trachybasaltic lamprophyric rock generally composed of augite and olivine with minor amounts of hornblende, biotite, orthoclase, plagioclase, and analcite; occurs as dikes in the Rico area.

Rico Mountain Complex (TKm,TKms): Predominantly monzonite and monzonite porphyry; generally gray with hydrothermal alteration to white, red, or yellow; composed of equal amounts of orthoclase and plagioclase, hornblende, and quartz with minor biotite and augite. Where phenocrysts are present, they are composed mainly of plagioclase and hornblende. The Rico Mountain Complex outcrops near the headwaters for the Dolores River and is the location for much of the mining in the Rico area. Several mines exist within the Silver Creek area and contribute mercury, cadmium (Cd), lead (Pb), manganese (Mn), and zinc (Zn) to existing surface water.

Mancos Shale (Km): Gray, fissile marine shale which is a slope former; contains sparse thin calcareous sandstones and limestone beds; approximately 2,000 to 3,000 feet in thickness; located generally to the west and south of the study area.

Dakota and Burro Canyon Formations (Kdb): Light gray to brown marine and fluvial quartzose sandstone and coarse conglomerate occurring in thick beds; lenticular; contains beds of purple non-bentonitic siltstone, shale, and mudstone.

Junction Creek Sandstone, Wanakah Formation and Entrada Sandstone Undifferentiated (Jjwe): Consists of predominantly sandstone with individual members consisting of siltstone and limestone units; green to pink to red in color; eolian and marine deposition.

Morrison Formation (Jm): Dominantly fluvial, lacustrine sandstone and mudstone deposits; variegated green to purple color; bentonitic.

Dolores Formation (Trd): Bright red to orange fluvial siltstone, sandstone, and shale; up to 850 feet in thickness.

Cutler Formation (Pc): Continental sequence of beds with red, fine-grained nearshore deposits and alternating units of eolian deposits; sandstones may be arkosic.

Rico Formation (PPr): Light gray beds of cherty marine limestone, red-brown beds of fluvial sandstone, and minor red-purple beds of gypsiferous siltstone.

Hermosa Formation (PPh): Gray to light brown fossiliferous marine limestone and dolomite; crossbedded sandstone and siltstone with minor gray shale and gypsum. At Rico, metamorphosed chloritic rocks were noted. The salt bearing Paradox Member also exists at depth in the study area.

Elevated trace metal levels in the Fish Creek-Geyser Creek area may be associated with Tertiary and Tertiary/Cretaceous age intrusives. There is also faulting evidence near the Geyser Creek headwaters which could also contribute to trace metal accumulations, possibly through hydrothermal or ground-water action.

Cinnabar (HgS) is the only comparatively common mercury mineral. Cinnabar is known to deposit in hot springs, e.g., Steamboat Springs (Saupé, 1972). Saupé (1972) also lists a couple of rare mercury minerals known from the area around Keystone, including coloradoite (HgTe) and magnolite (Hg_2TeO_4).

Elevated trace metal levels in the Rico-Silver Creek area appear to be directly related to intrusive units within the area. Several mines exist within Silver Creek and emanate surface water into the creek. Elevated trace metal values in Rio Lado Creek may also be related to an intrusive dike in the area.

The complete mineralogy of the Rico Mining District has been described in McKnight (1974). The minerals, their occurrences, and their principal chemical components are included in appendix D. Saupé (1972) indicates that traces of mercury may occur in tetrahedrite and tennantite (in which case they are called schwazite and hermesite, respectively), penroseite, argyrodite, clausethalite, altaite, and sphalerite. Of these, the ones that have been observed or reported in the Rico Mining District by McKnight (1974) are flagged in appendix D. These include tetrahedrite and tennentite, argyrodite, and sphalerite. An assay of the

Rico tetrahedrite-tennentite composition is given in McKnight (1974), table 4, page 60; no mercury is reported but the minimum concentration of any element is illustrated by Bi, which is reported as <0.1 percent.

The geology and ore deposits of the La Plata Mining District, which encompass the La Plata Mountains, are described by Eckel (1949). The mines of the Bear Creek District, which is included within the La Plata District, are also described by Eckel (1949). Bear Creek empties into the Dolores River about 10 miles down-stream from Rico.

Eckel (1949) in his mineralogical description of the La Plata District indicates that native Hg, cinnabar, and amalgam (Au,Ag,Hg) were widespread in the La Plata District. Native Hg was associated with amalgam and tellurides, leading to the hypothesis that the native Hg originated from the breakdown of coloradoite. The La Plata District was most productive of gold, and the Hg was associated with gold ores. The Bear Creek District was associated with copper (Cu) deposits (Goodard, 1949) and does not seem a more likely source of the Hg in the Dolores River than other areas of the basin.

LAND USE

The Dolores River basin above Dolores is approximately 90 percent forest and natural meadows. Most of the land is in public ownership, administered by the United States Forest Service. The valley floor of the Dolores River from about Rico downstream and the valley floor of the West Fork is mostly in private ownership and used for ranching. However, from the confluence with the West Fork to the town of Dolores, the valley is becoming increasingly developed. Relatively extensive stream channel modifications have resulted from the development, and along with other forces, has resulted in an unstable channel from the confluence to the town of Dolores.

Significant hard rock mining and milling activities have occurred in the Dolores Basin. Most of the activity was concentrated in the Rico area, including Silver Creek, Sulphur Creek, Horse Creek, and along the mainstem of the Dolores River. A small amount of hard rock mining occurred near Dunton on the West Fork. Gravel mining has historically occurred along the river from the confluence with the West Fork downstream. One gravel mine is currently in operation.

Chapter III

WATER AND SEDIMENT SAMPLING

Reclamation began collecting samples from a variety of sites in the Dolores River basin of Colorado in 1989. Sampling began after elevated mercury levels observed in fish in Reclamation's McPhee Reservoir prompted the Colorado Department of Health to post warnings against the consumption of large amounts of fish from the reservoir. The purpose of the sampling of water and sediment was to identify the source of the mercury. The results of the sampling effort are to be reported here. All sample sites are shown in figure 1.

Sediment site designations take a somewhat different form on data reports prepared at different times. In the initial report prepared shortly after the results were received from the laboratory, sediment site designations were given the format, D#S, beginning at site D2S and ending with D12S. The analytical results on the Durango Projects Office form prepared in 1990 gave the site designation in the format D-#, beginning with site D-1 and ending with site D-11 (table 1). The latter designation will be used in the report. Sites D-12 through D-16 were added during the October 1993 sampling, these locations are also shown in table 1. The water quality monitoring sites have been identified as DRDOL##T and include sites DRDOL01T through DRDOL52T. For the sake of simplicity only the numbers 1 through 52 will be used in this report. A complete list of the water quality monitoring sites appears in table 2. All sites are shown schematically on figure 1.

Table 1.—Sediment sample sites on the Dolores River

D-1	Dolores River above Barlow Creek
D-2	Dolores River 2 miles above Rico
D-12	Dolores River at Peterson Slide
D-3	Dolores River at bridge above Rico
D-5	Silver Creek near mouth
D-4	Dolores River below Silver Creek
D-6	Dolores River below Rico near graveyard
D-7	Dolores River above Scotch Creek
D-8	Scotch Creek
D-9	Dolores River at Montelores Bridge
D-16	Dolores River below Bear Creek
D-10	Dolores River above West Dolores River
D-15	West Dolores River near mouth
D-14	Dolores River below Wallace Reservoir
D-11	Dolores River at Dolores
D-13	Same as D-11

Samples were first collected for the Dolores River Mercury Study in September 1989. Both water and sediment samples were collected. Water samples were analyzed by Casa del Sol Laboratories in Durango, Colorado. The sediment samples and two splits of the water samples were analyzed by the USGS Geochemistry Laboratory in Denver. Subsequently only water samples were

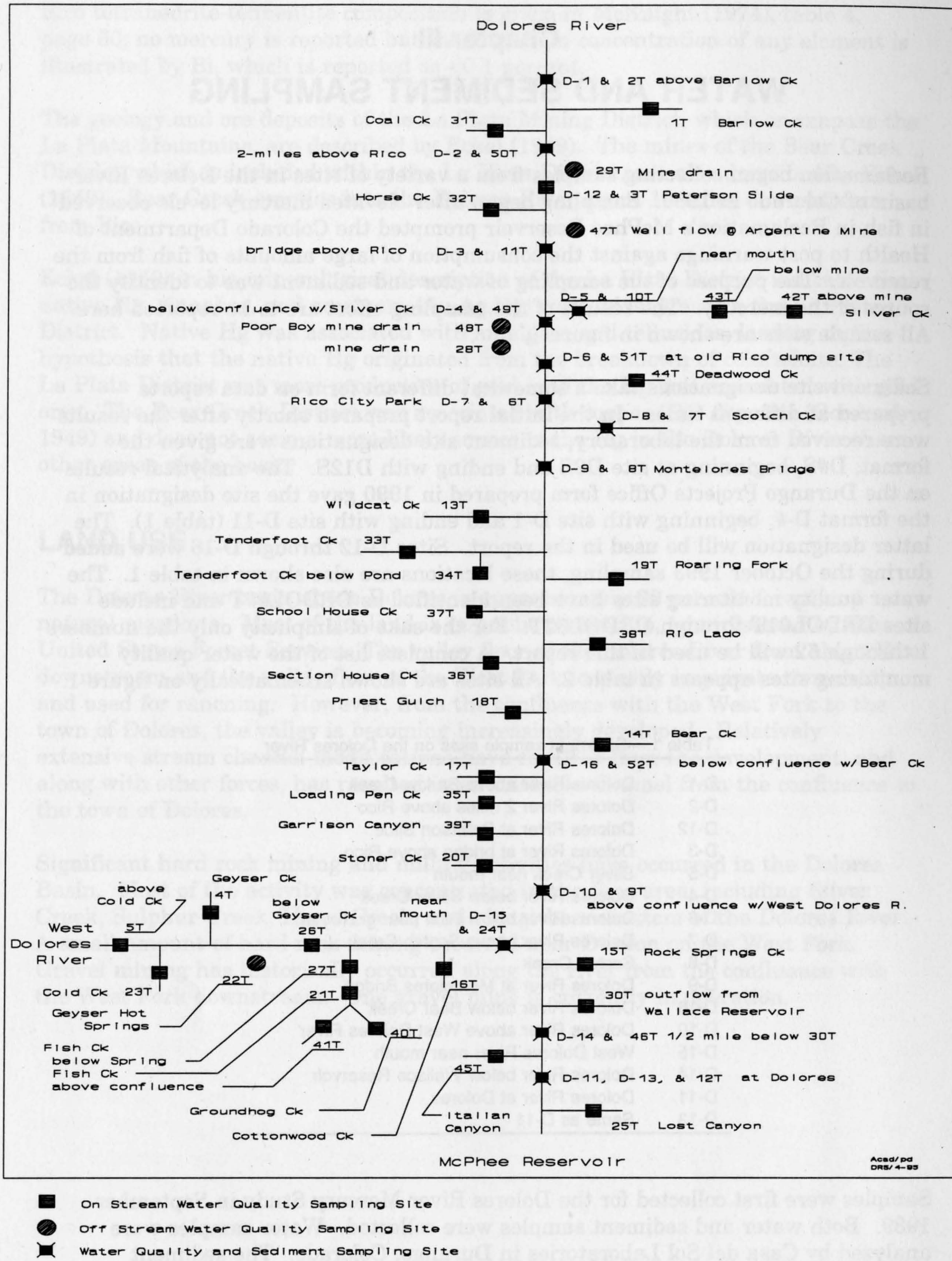

Figure 1.—Schematic map of Dolores Basin sample site locations.

Table 2.—Water quality sample sites

Site	Station location
01T	Barlow Creek
02T	Dolores River above Barlow Creek
03T	Dolores River at Peterson Slide
04T	Geyser Creek
05T	West Dolores above Cold Creek
06T	Dolores River at Rico City Park
07T	Scotch Creek
08T	Dolores River at Montelores Bridge
09T	Dolores River above West Dolores River
10T	Silver Creek near mouth
11T	Dolores River at bridge above Rico
12T	Dolores River at Dolores
13T	Wildcat Creek
14T	Bear Creek
15T	Rock Springs Creek
16T	Cottonwood Creek
17T	Taylor Creek
18T	Priest Gulch
19T	Roaring Fork
20T	Stoner Creek
21T	Fish Creek below confluence
22T	Geyser Hot Springs
23T	Cold Creek
24T	West Dolores River near mouth
25T	Lost Canyon
26T	West Dolores River below Geyser Creek
27T	Fish Creek below spring
28T	Mine drain below Silver Creek
29T	Mine drain near Peterson Slide
30T	Outflow from Wallace Reservoir
31T	Coal Creek
32T	Horse Creek
33T	Tenderfoot Creek
34T	Tenderfoot Creek below pond
35T	Loading Pen Creek
36T	Section House Creek
37T	School House Creek
38T	Rio Lado
39T	Garrison Canyon
40T	Groundhog Creek
41T	Fish Creek above confluence
42T	Silver Creek above mine
43T	Silver Creek below mine
44T	Deadwood Creek
45T	Italian Canyon
46T	Dolores River ½ mile below 30T
47T	Well flow at Argentine Mine
48T	Poor Boy Mine drain
49T	Dolores River below Silver Creek
50T	Dolores River 2 miles above Rico
51T	Dolores River at old Rico dump site
52T	Bear Creek below confluence

collected. Field determinations included discharge, water temperature, electrical conductivity (EC), and hydrogen-ion concentration (pH). Samples were analyzed for total dissolved solids (TDS), major cations, and anions and a variety of heavy metals and other trace elements. In addition to mercury (Hg), analytes (potential contaminants) included:

> Silver (Ag), aluminum (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), thallium (Tl), vanadium (V), and zinc (Zn).

On occasion, water sample analyses also included cobalt (Co), lithium (Li), silicon (Si), tin (Sn), and uranium (U). Sediment samples were analyzed for major cations and the trace elements listed above.

Chapter IV

RESULTS

WATER

The mercury results from all water analyses performed during the study are presented in appendix A. The initial results showed mercury below detectable levels. However, the limit of detection in September 1989 was relatively high at 1 µg/L. All samples were totals. In November 1989, only dissolved mercury was determined; none was observed at a minimum detectable concentration of 0.5 µg/L. The minimum detectable mercury concentration was subsequently decreased to 0.1 µg/L during 1990 and 1991. However, an unacceptably high number of samples showed greater concentrations of dissolved mercury than there was total mercury in the samples. This was particularly true during July 1990 and May 1991. Different laboratories were used to analyze the three sets of samples collected in April, July, and September 1992. The April and July 1992 data are the most internally consistent and will be used exclusively in the evaluation of mercury in water. The September 1992 report gives a mercury detection limit of 0.03 µg/L; however, no mercury was observed in any of the samples despite the lower detection limit. Alternatively, the detection limit for many of the other trace elements increased, and those were not measurable either. Examples of those latter trace elements include copper with a detection limit at 25 µg/L and arsenic at 10 µg/L.

As noted above, many of the mercury analyses are not of satisfactory quality to be useful in identifying and evaluating the problem of mercury contamination of fish in McPhee Reservoir; so the 1992 data will be emphasized. The results of the chemical analysis of the same samples for other contaminants do appear to be satisfactory. Although the other contaminants do not seem to be at problem levels in the water or the fish in McPhee Reservoir, they may provide some insight into the origin of the mercury. Selected other heavy metals and possible contaminants, e.g., arsenic, will also be evaluated.

Dissolved and total mercury results from the samples collected during April 1992 are shown on figure 2. Most of the sites show no measurable mercury. Only those sites where the histogram touches or rises above the horizontal line (the detection limit) have measurable or reportable mercury. Site 5 (or 05T), which is the farthest upstream sampling site on the West Dolores River, had a dissolved mercury concentration of 0.25 µg/L, but there was no total mercury sample. At site 8, the mainstem of the river at the Montelores Bridge, both the dissolved and total mercury concentrations were 0.25 µg/L. All other dissolved mercury concentrations were below detectable levels (figure 2).

The peak total mercury concentration at any site during April was 0.3 µg/L at sites 21 and 38. Site 21 is located on Fish Creek, a tributary to the West Dolores River, below its confluence with Groundhog Creek, which was not sampled during April. Site 38 is the Rio Lado, a left-bank tributary to the Dolores River (figure 1). There were four sample sites that had mercury at the minimum detectable

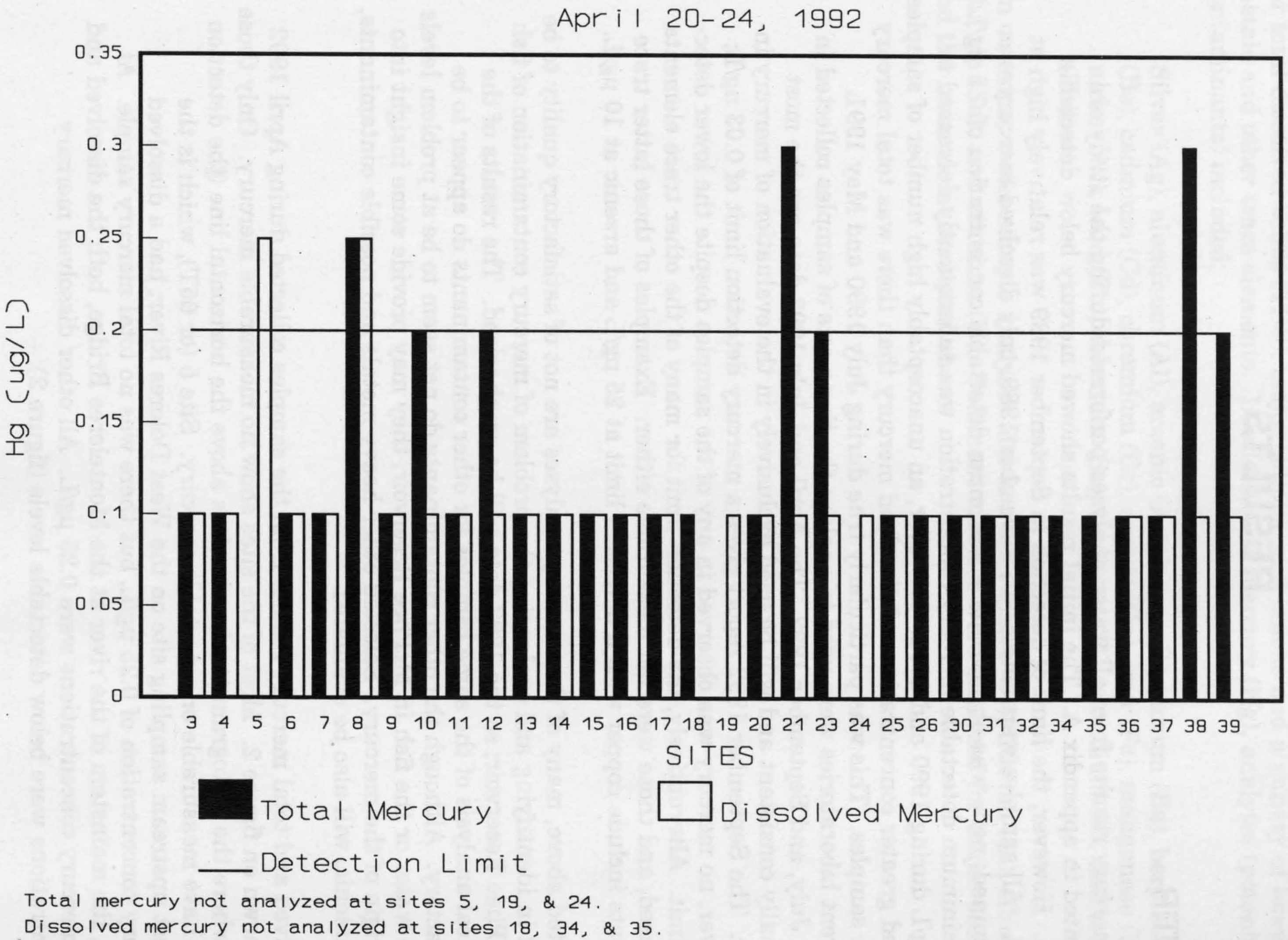

Figure 2.—Mercury concentrations at all sampling sites during April 1992.

concentration of 0.2 µg/L. Those included Cold Creek, another tributary to the West Dolores River; Garrison Canyon, a small mainstem tributary near Stoner Creek; Silver Creek, at the site where the sediment sample was collected; and the mainstem of the Dolores River near McPhee Reservoir. The April 1992 water samples indicate that, in addition to Silver Creek, there are numerous sources of mercury in the upper Dolores Basin and many of them are located well downstream from Silver Creek. The presence of mercury above the EPA recommended criterion to prevent mercury bioaccumulation to its Food and Drug Administration (FDA) action level of 1 part per million (ppm) supports the hypothesis that the mercury originates from the river rather than from sources within the reservoir itself.

The July results did have one sample in which the dissolved mercury was reported as being greater than the total mercury (figure 3). At site 20, which is located in Stoner Creek, the total mercury was reported as <0.2 µg/L, while the dissolved mercury was reported as being 0.2 µg/L. Presumably both are near the limits of detection, and the mercury is all, or nearly all, dissolved. Only one other sample (site 22) had a detectable concentration of dissolved mercury.

Of the 41 sites sampled (excluding site 20) during July 1992, results from 32 show the total mercury to be less than its minimum detectable concentration of 0.2 µg/L (figure 3). The peak mercury concentration was 0.35 µg/L at site 22. Site 22 is located at the Geyser Hot Springs (figure 1). Apparently, over half of the mercury is dissolved. Of the remaining samples, half were at the minimum detectable concentration of 0.2 µg/L, including sites 8, 10, and 12, as in April, and site 44, Deadwood Creek, a left-bank tributary near Silver Creek and just upstream from site 8. Three sites equaled the peak mercury concentration of 0.3 µg/L observed in April. Those sites included numbers 28 and 29, two mine drains near Silver Creek, and site 38, which was at the same concentration as it had been in April. Site 25, which is a small left bank tributary between site 12 and McPhee Reservoir, exhibited a mercury concentration of 0.25 µg/L.

Several of the sites that had relatively high concentrations of mercury are not primary tributaries to the Dolores River. Those include the site at the Geyser Hot Springs and the one on Fish Creek, both of which are tributary to the West Dolores River. The West Dolores River did not show any measurable Hg at the site (24) near its mouth. Because of this, there is not an apparent effect of the loadings from West Dolores River tributaries. However, the Hg concentration at which bioaccumulation to the FDA action level of 1 ppm in fish may occur has been estimated by the EPA (1989) to be 0.012 µg/L, which is less than one-tenth of the Hg detection limit of 0.2 µg/L for most of the samples collected during this study. For this reason, the West Dolores River cannot be eliminated as a potential source of the Hg in the McPhee Reservoir fish. There is a high probability that there is mercury originating from the West Dolores, but the amount cannot be quantified.

As was noted above, the minimum detectable level for mercury was reduced to 0.03 µg/L in the September 1992 samples. There was no detectable total or dissolved mercury in any of the samples. This could indicate that the presence of mercury in the Dolores River is either flow related or seasonal, the two of which are not necessarily independent.

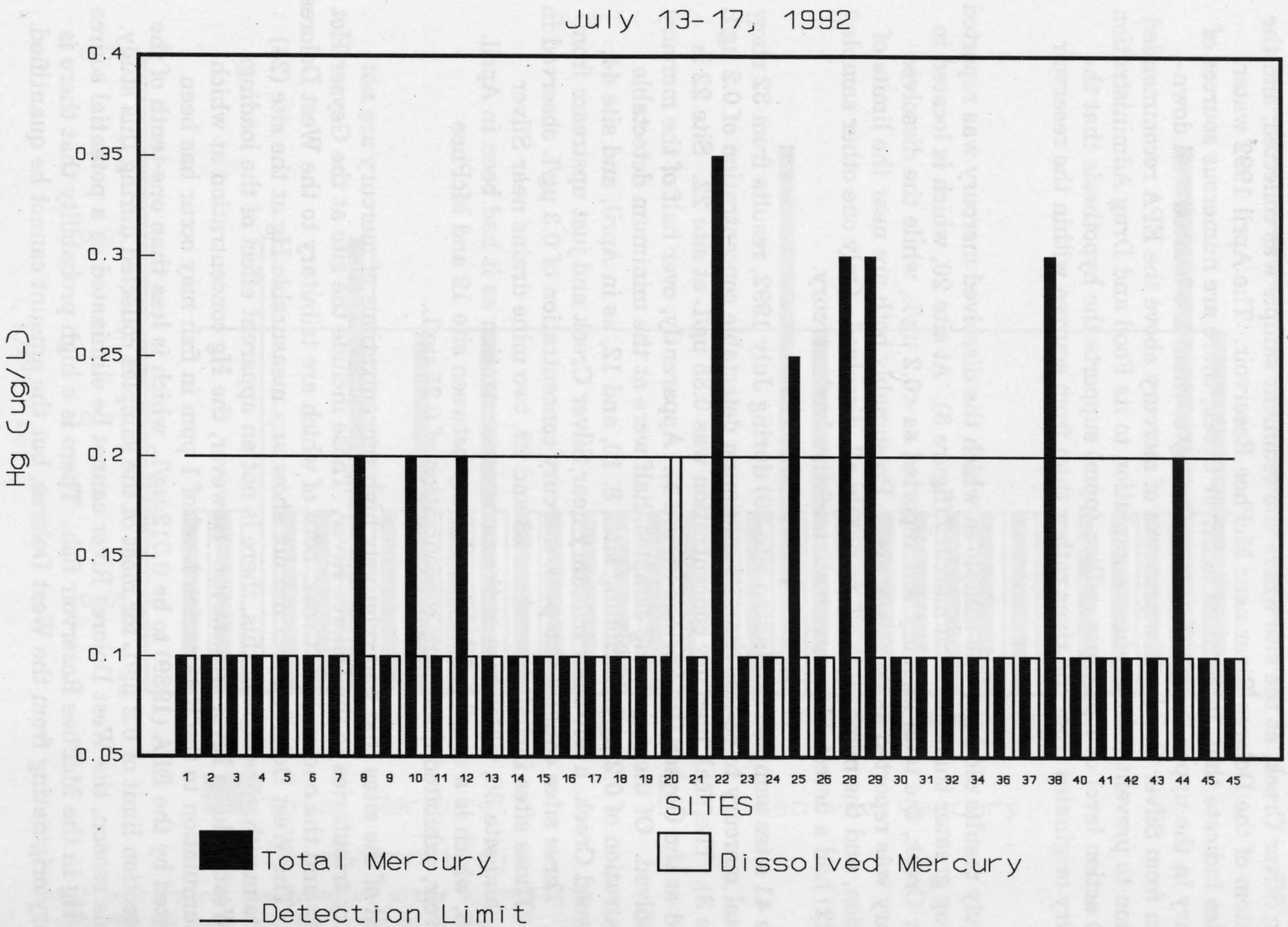

Figure 3.—Mercury concentrations at all sites sampled during July 1992.

Measurable concentrations of total iron and manganese are present at most sites on most occasions. Although the two heavy metals are not particularly toxic, both are frequently associated with mine drainage, which is the apparent source of most of the mercury. Total and dissolved iron and total manganese concentrations during April 1992 are shown on figure 4. Dissolved manganese was below detectable levels in the vast majority of samples and has not been plotted. Total manganese is below detectable concentrations at a number of sites; for illustrative purposes, those results are plotted as one-half the detection limit of 50 µg/L.

The peak total and dissolved iron concentrations during April were observed at site 25, the site on Lost Canyon Creek (figure 4). The total iron in the sample from Silver Creek near its mouth was nearly as great as that in the Lost Canyon Creek sample, but the dissolved fraction was much lower in the Silver Creek sample. Manganese was somewhat higher in Silver Creek than in Lost Canyon Creek.

Dissolved iron tends to be high in mine drainage near its source, but it decreases rapidly as the drainage becomes neutralized. Both samples with high total iron concentrations were slightly to very alkaline when they were collected. The field pH of the samples from sites 10 and 25 were 7.4 and 8.5, respectively. The field electrical conductivity at site 25 was 76 micro-siemens per centimeter (µS/cm), indicating that despite the relatively high concentrations of trace elements, the water is relatively low in salts. The TDS was only 82 milligrams per liter (mg/L) at site 25. Ordinarily, the TDS is approximately 0.7 the EC. When the TDS is greater than the EC, the indication is that there is a relatively large concentration of unionized dissolved solids, which is typically due to undissociated silica (SiO_2). However, there were no SiO_2 analyses during April 1992.

The site 25 result was further analyzed using the chemical equilibrium program, WATEQ. An initial simulation was run with the SiO_2 set to 0.2. The computed TDS was 62.5. The computed EC was 90 µS/cm. As was noted above, the field EC was 76, but the laboratory EC was even lower at 64 µS/cm. The TDS was adjusted by adding 20 mg/L of SiO_2. The WATEQ results indicated that essentially all of the SiO_2 remained in the aqueous phase as undissociated H_4SiO_4 with only a minor concentration of the first ionization, $H_3SiO_4^{-1}$. Iron was projected to be predominantly (80 percent [%]) in the form of the anionic hydroxide, $Fe(OH)_4^{-1}$, which would be expected to be dissolved. The analytical dissolved iron was 59% of the total. However, the analytical dissolved iron is only an approximation based on filter size. The actual dissolved iron would be expected to be somewhat lower. Any adsorbed iron would be in the ionic (dissolved) form in WATEQ, but would be functionally particulate in a filtered sample. Consequently, the WATEQ results are not directly comparable to the analytical results. The WATEQ results do indicate that the size of the dissolved fraction in the analytical result is entirely possible.

The July 1992 samples included two mine drains in the vicinity of Silver Creek. Site 28 is located downstream from Silver Creek, and site 29 is located upstream from Silver Creek in the area of the Peterson Slide. The drains carry 3 to 4 mg/L of total iron, much of which is dissolved (figure 5). Because of the very high iron concentration of the drains, the remaining samples are limited to a somewhat compressed scale. Nevertheless, the results are very much like those of April in

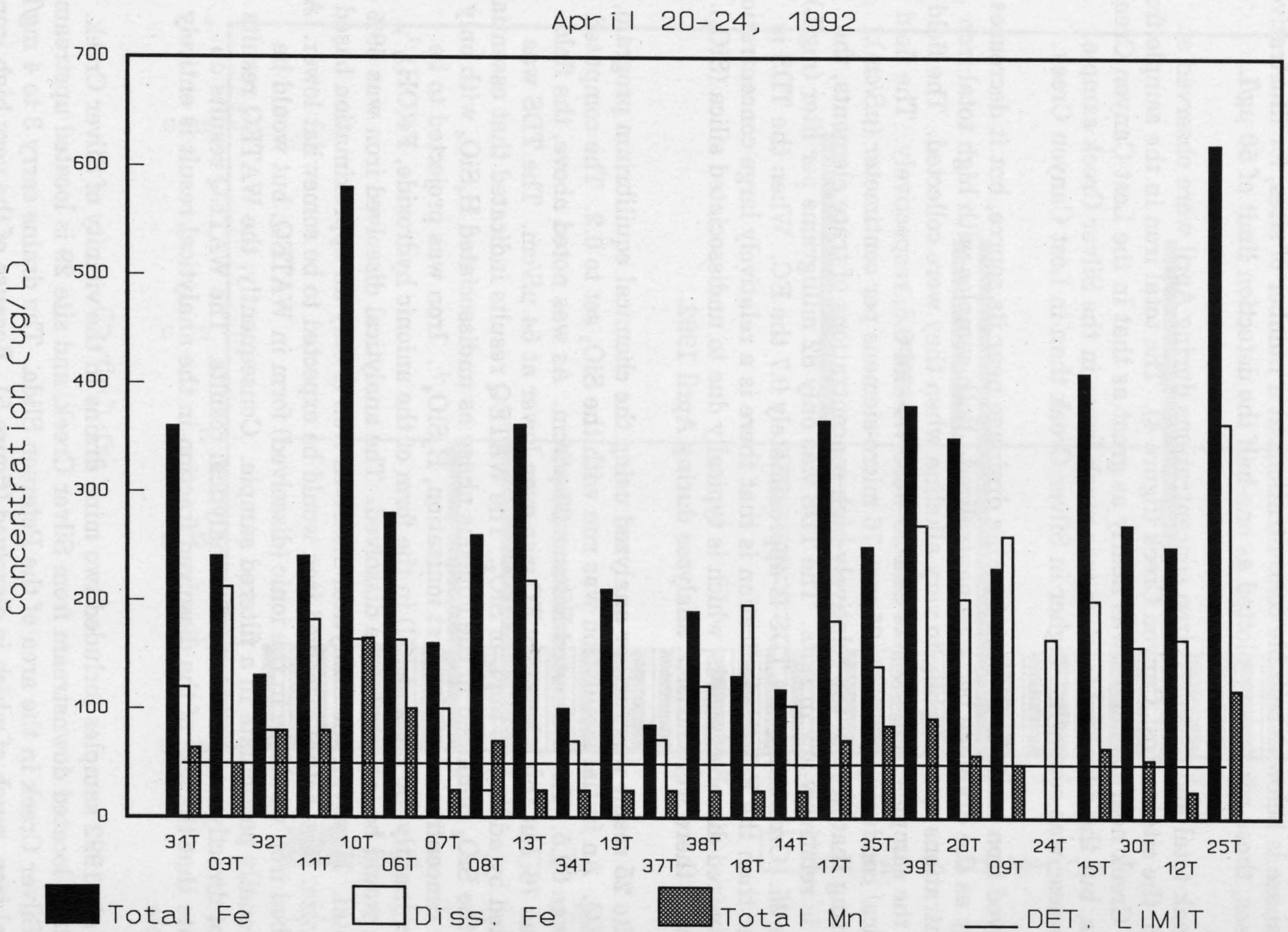

Figure 4.—Iron and manganese concentrations in the Dolores River Basin during April 1992.

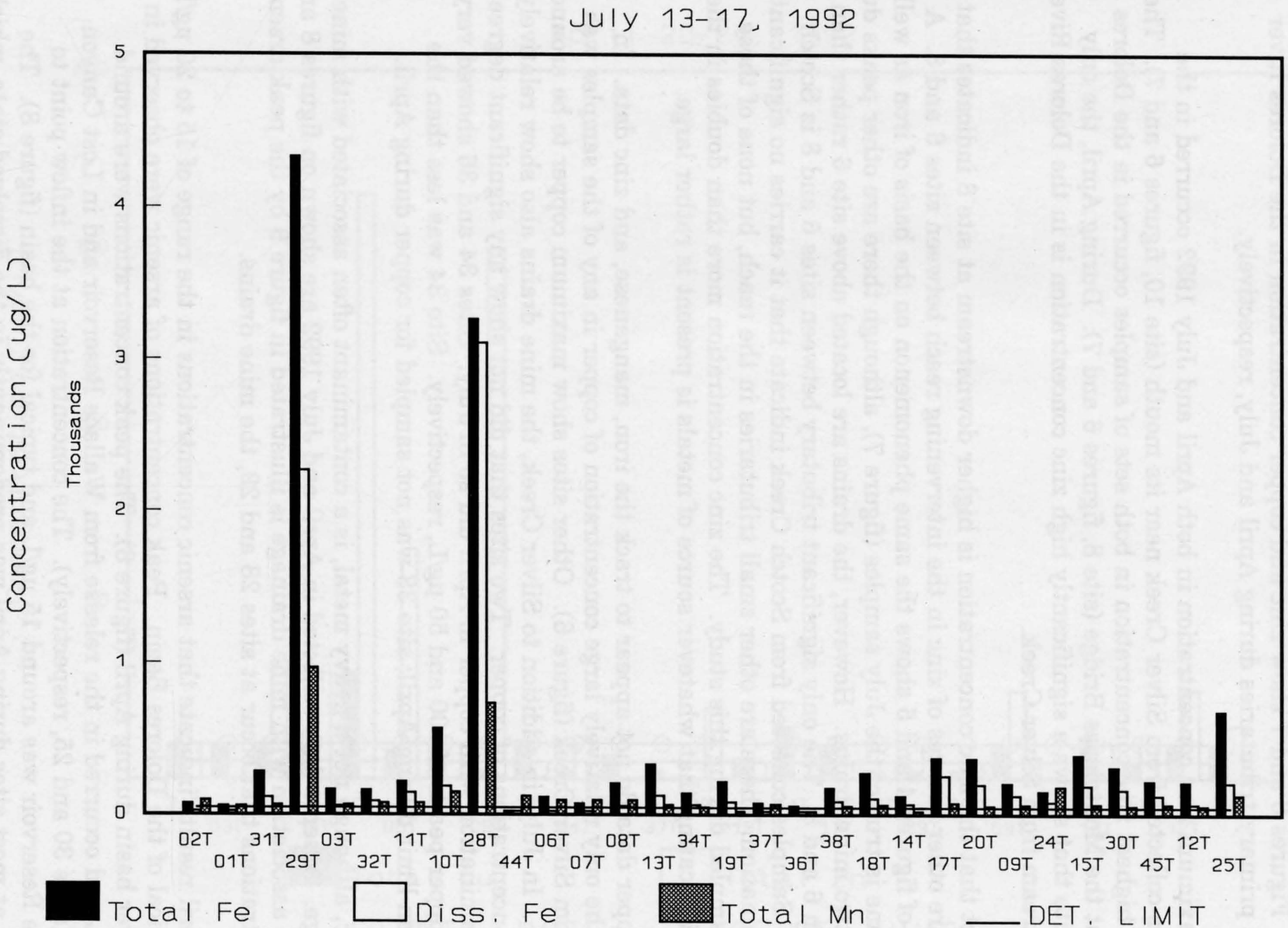

Figure 5.—Iron and manganese concentrations in the Dolores River Basin during July 1992.

that the Silver Creek and Lost Canyon Creek total iron are greater than that of other sites, and Lost Canyon Creek showed the maximum of any of the sites other than the mine drains. The peak iron concentrations in Silver Creek and Lost Canyon Creek are of approximately the same magnitude as those of April as well.

Zinc and copper are common associates of iron and manganese in mine drainage water. Figures 6 and 7 show zinc and copper concentration in the Dolores River and its primary tributaries during April and July, respectively.

The maximum zinc concentration in both April and July 1992 occurred in the samples collected from Silver Creek near its mouth (site 10, figures 6 and 7). The second highest zinc concentration in both sets of samples occurred in the Dolores River at the Montelores Bridge (site 8, figures 6 and 7). During April, the only other site that shows a significantly high zinc concentration is in the Dolores River downstream from Silver Creek.

The fact that the zinc concentration is higher downstream at site 8 indicates that there are other sources of zinc in the intervening reach between sites 6 and 8. A review of figures 4 and 5 shows the same phenomenon on the basis of iron as well. The same is true of the July samples (figure 7), although there are other peaks due to the two mine drains. However, the drains are located above site 6 rather than between 6 and 8. The only significant tributary between sites 6 and 8 is Scotch Creek. Samples collected from Scotch Creek indicate that it carries no significant contamination. There are other small tributaries in the reach, but none of those were sampled during this study. The zinc concentration more than doubles in the reach, indicating that whatever source of metals is present is rather large.

The copper data do not appear to track the iron, manganese, and zinc data. In April, the only relatively large concentration of copper in any of the samples was that from Silver Creek (figure 6). Other sites show maximum copper to be around 10 µg/L. In July, in addition to Silver Creek, the mine drains also show relatively high concentrations of copper. Two sites that did not show any significant degree of contamination with copper in April did so in July. Sites 34 and 36 showed very large copper peaks of 100 and 50 µg/L, respectively. Site 34 was less than the detection limit during April; site 38 was not sampled for copper during April.

Arsenic, although not a heavy metal, is a contaminant often associated with mine drainage. Arsenic data collected in April and July 1992 are shown on figures 8 and 9. The association with mine drainage is illustrated in figure 9 by the peak arsenic concentrations that occur at sites 28 and 29, the mine drains.

The April results indicate that arsenic concentrations in the range of 15 to 20 µg/L are typical of the Dolores Basin. Peak concentrations of arsenic were observed in the lower basin during April (figure 8). The peak concentrations were around 40 µg/L and occurred in the release from Wallace Reservoir and in Lost Canyon Creek (sites 30 and 25, respectively). The concentration at the inflow point to McPhee Reservoir was around 15 µg/L and typical for the basin (figure 8). The arsenic at most sites during April was predominantly in the dissolved state, which is to be expected in well oxygenated water.

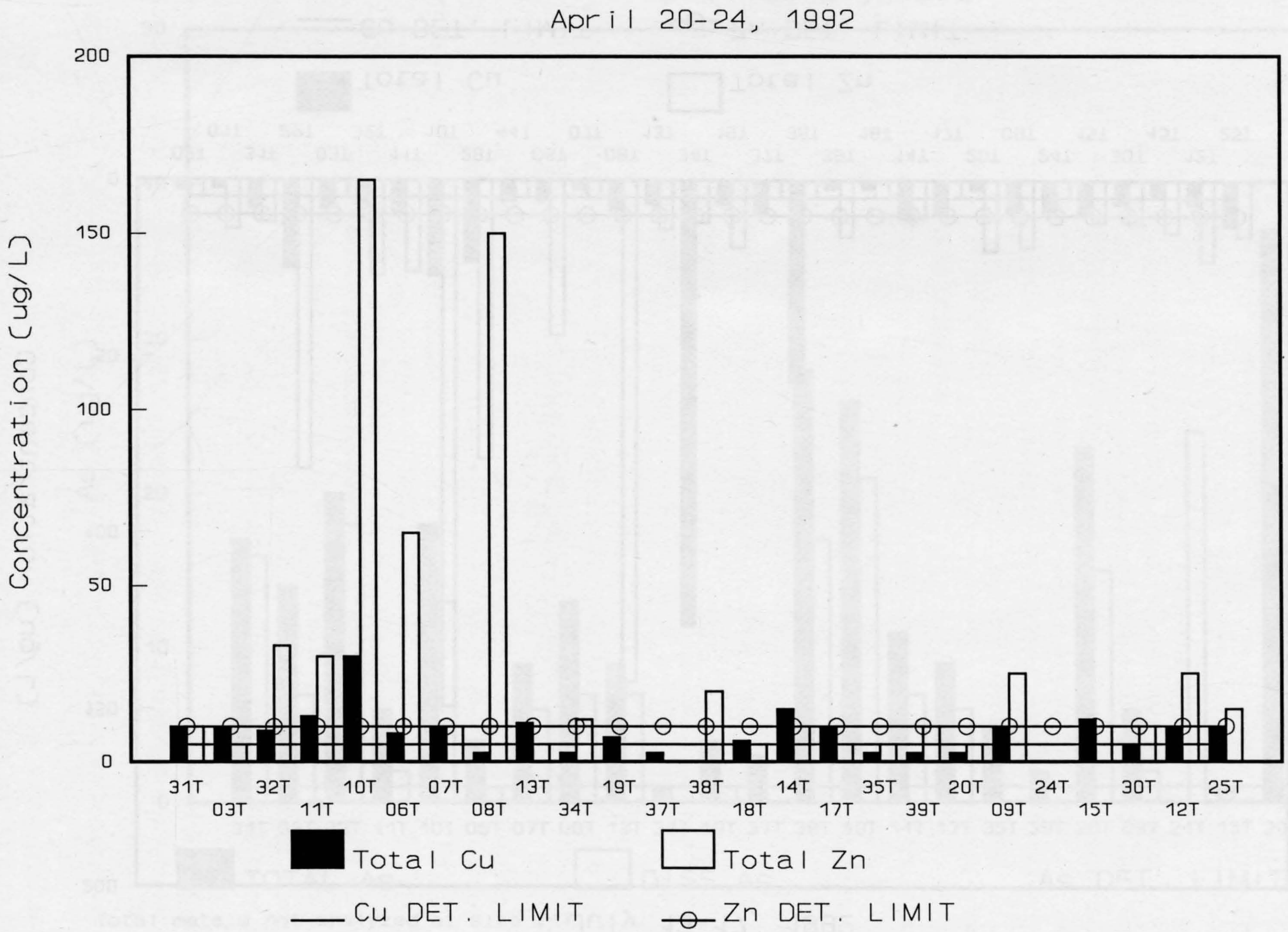

Figure 6.—Copper and zinc concentrations in the Dolores River Basin during April 1992.

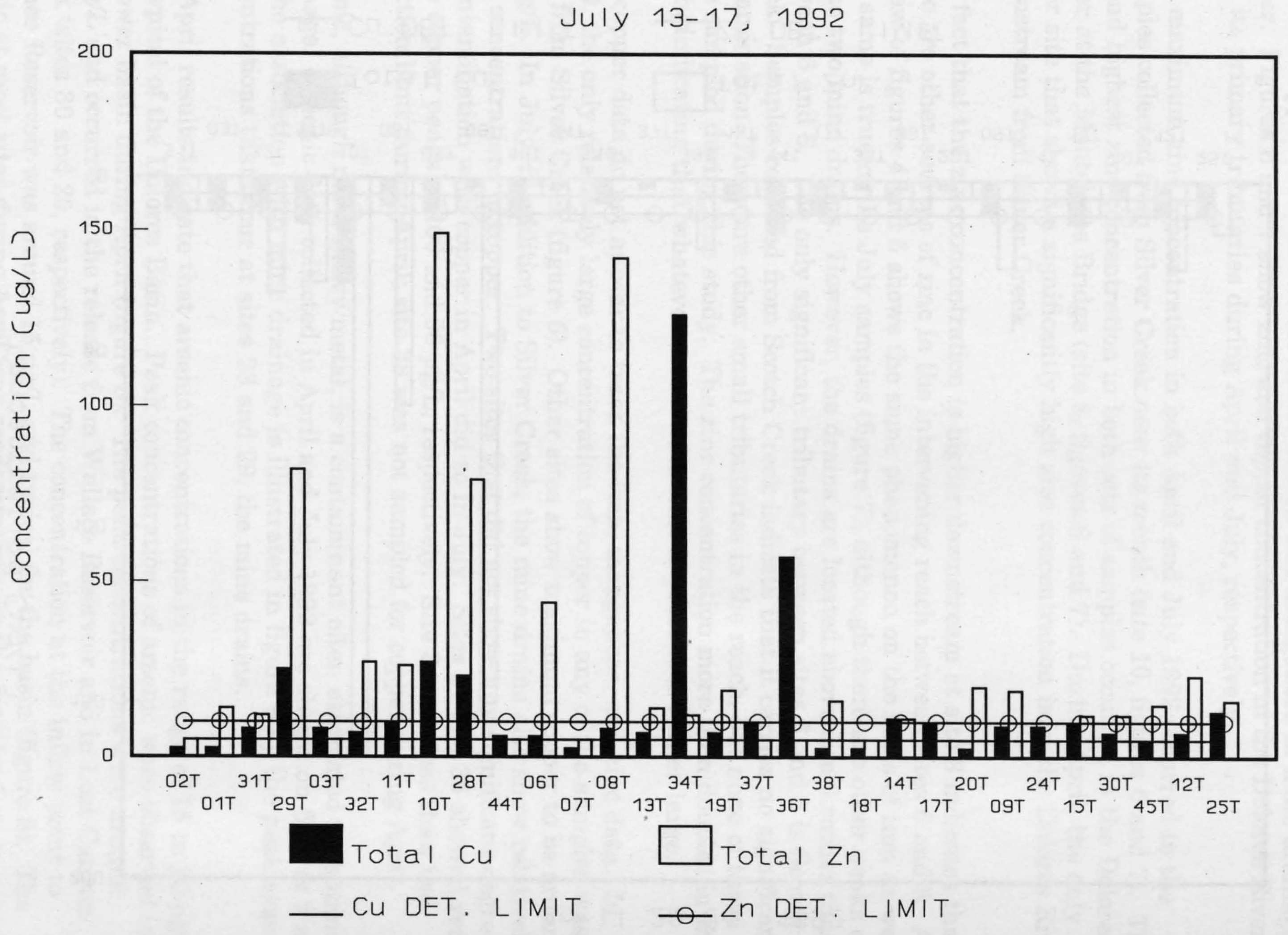

Figure 7.—Copper and zinc concentrations in the Dolores River Basin during July 1992.

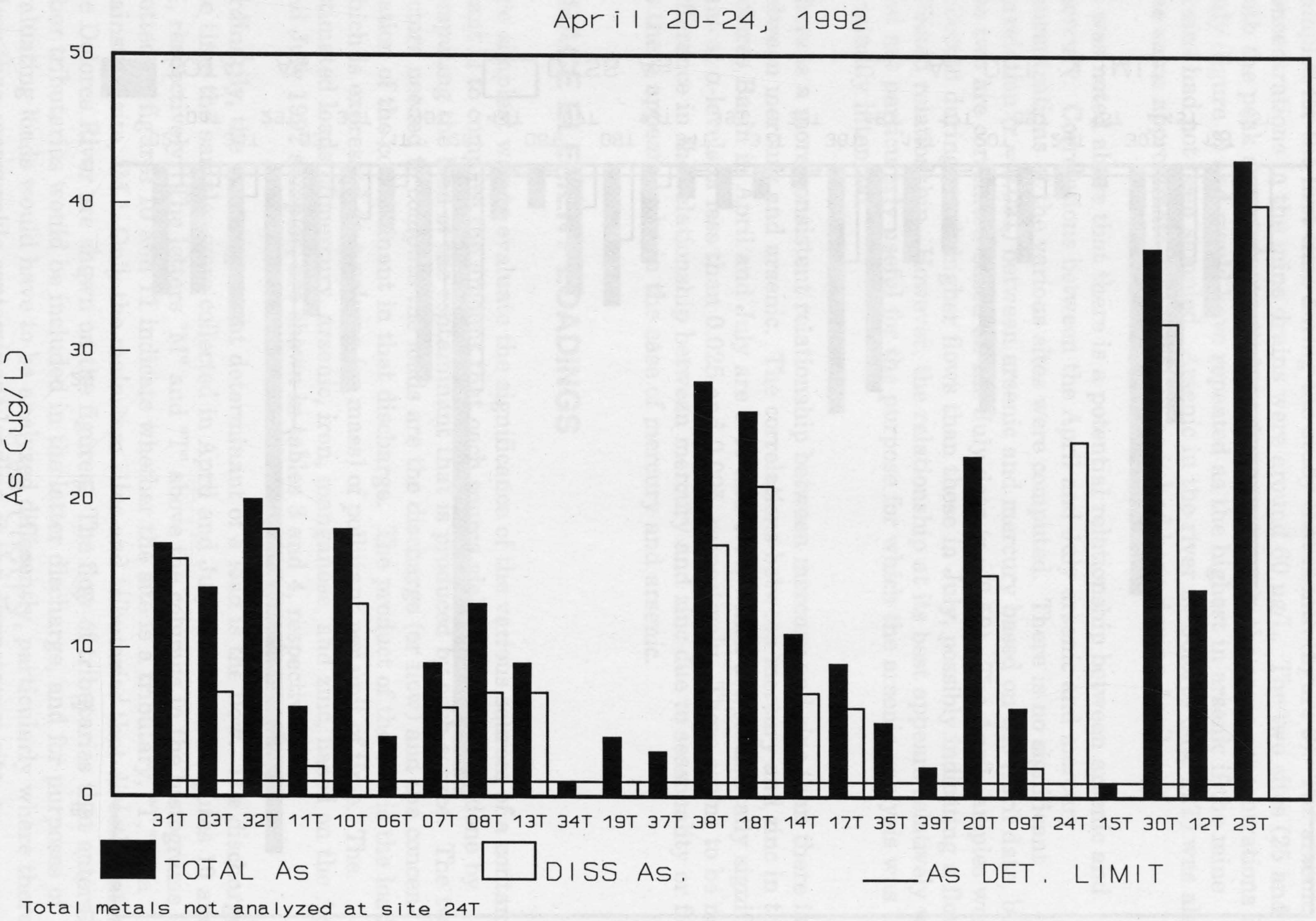

Figure 8.—Arsenic concentrations at selected sites in the Dolores River Basin during April 1992.

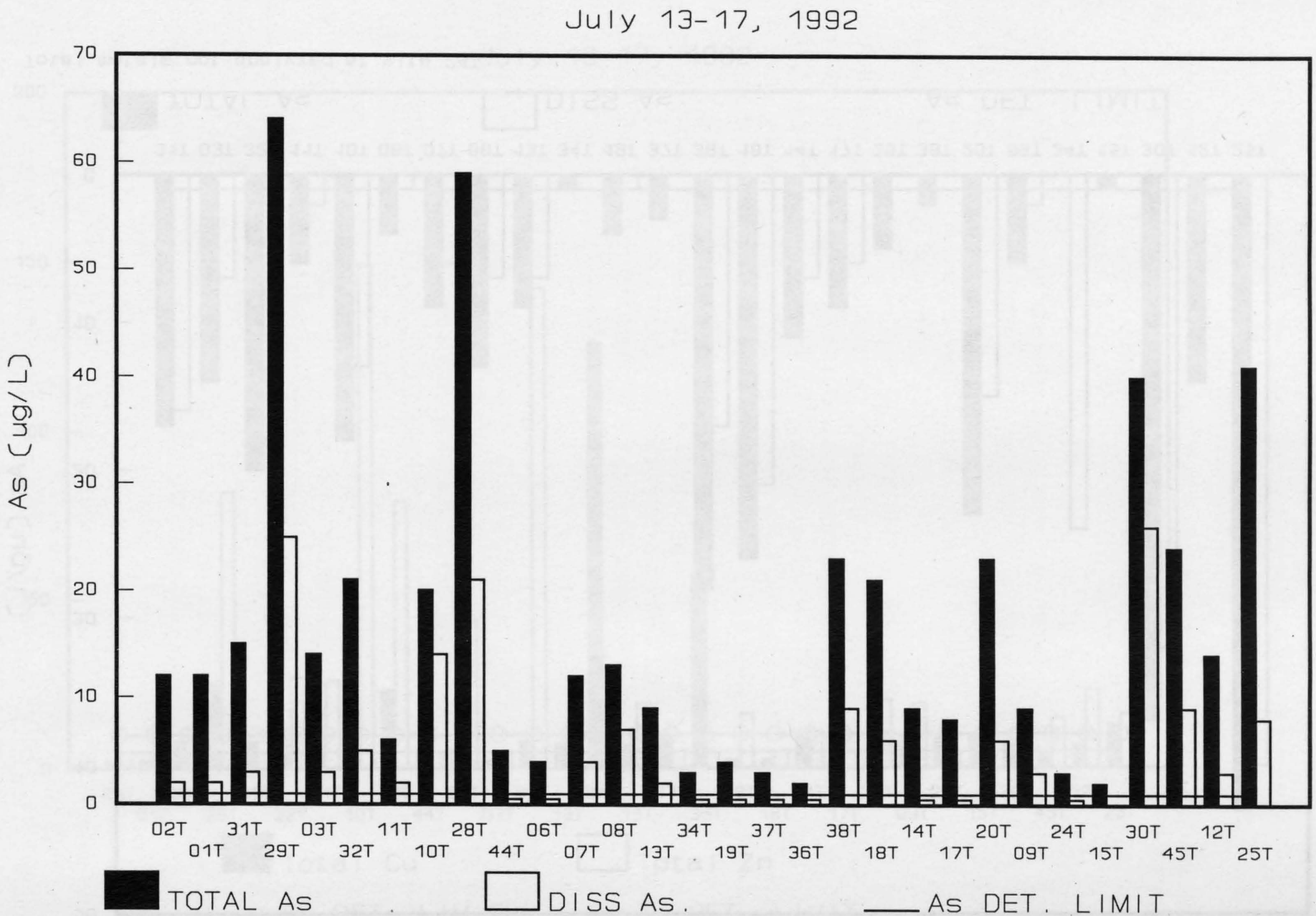

Figure 9.—Arsenic concentrations at selected sites in the Dolores River Basin during July 1992.

The peak arsenic during July occurred in the two mine drains that had been sampled for the first time during the study that month (figure 9). The arsenic concentrations in the mine drains were around 60 µg/L. The two sites (25 and 30) with the peak arsenic in April showed approximately the same concentrations in July (figure 9) and would have repeated as the highest in arsenic if the mine drains had not been sampled. Arsenic in the river at Dolores (site 12T) was also at the same approximate concentration as it had been during April.

It was noted above that there is a potential relationship between arsenic and mercury. Correlations between the April and July arsenic and mercury concentrations at the various sites were computed. There is no significant correlation ($r = 0.091$) between arsenic and mercury based on the April data, but the two are correlated based on the July data ($r = 0.58$). The April samples were collected during much higher flows than those in July, possibly indicating a flow-affected relationship. However, the relationship at its best appears relatively weak and not particularly useful for the purpose for which the arsenic analysis was originally intended.

There is a more consistent relationship between mercury and zinc than there is between mercury and arsenic. The correlations between mercury and zinc in the Dolores Basin in April and July are 0.40 and 0.44, which are statistically significant at α-levels of less than 0.025 and 0.005, respectively. There seems to be no difference in the relationship between mercury and zinc due to seasonality or flow as there appears to be in the case of mercury and arsenic.

TRACE ELEMENT LOADINGS

The simplest way to evaluate the significance of the various sources of a contaminant is to compare the amount that each source yields. This can be done by computing the load of the contaminant that is produced by each source. The two factors needed to compute the loads are the discharge (or flow) and the concentration of the contaminant in that discharge. The product of the two is the load, which is expressed as a volume (or mass) of pollutant per unit of time. The estimated loads of mercury, arsenic, iron, manganese, and zinc, based on the April and July 1992 samples, are shown in tables 3 and 4, respectively.

Ordinarily, the most important determinant of a load is the flow. The discharge at the time the samples were collected in April and July is shown in figures 10 and 11, respectively. The letters "M" and "T" above the columns in the histograms plotted on figures 10 and 11 indicate whether the site is a tributary, "T," or a mainstem site, "M." Only the mainstem sites and tributaries that directly enter the Dolores River are shown on the figures. The flow of tributaries that enters other tributaries would be included in the latter discharge, and for purposes of evaluating loads would have to be analyzed differently, particularly where there is a less than measurable contaminant loading at the downstream site, a phenomenon that is fairly common in dealing with mercury. If a source makes an unmeasurable contribution at the farthest downstream measuring point, it may not be significant to the overall problem, which is centered on McPhee Reservoir.

Table 3.—Loads of selected metals and arsenic at sites sampled during April 1992 in the Dolores River Basin

				Contaminant loadings				
Date		Ft^3/s	Site	Hg-load (lb/d)	As-load (lb/d)	Fe-load (lb/d)	Mn-load (lb/d)	Zn-load (lb/d)
23-Apr-92	T2	4.0	33T		0.1295	1.94		
24-Apr-92	T2	21.0	23T	2.27E-02	1.1330	56.65	9.404	1.13
24-Apr-92	T2	1.0	04T			1.13		
24-Apr-92	T2		26T					
22-Apr-92	T2	27.0	16T		1.0197	36.42		
24-Apr-92	T2	75.0	21T	1.21E-01	5.2603	97.11		6.47
24-Apr-92	T2	1.0	36T					
24-Apr-92	T2		05T					
23-Apr-92	1	14.0	31T		1.2840	27.19	4.834	0.76
23-Apr-92	2		03T					
23-Apr-92	3	3.0	32T		0.3237	2.10	1.295	0.53
23-Apr-92	4		11T					
23-Apr-92	5	5.0	10T	5.40E-03	0.4856	15.65	4.451	4.45
23-Apr-92	6		06T					
22-Apr-92	7	19.0	07T		0.9226	16.40		1.03
22-Apr-92	8	143.0	08T	1.93E-01	10.0296	200.59	54.005	115.73
22-Apr-92	9	9.0	13T		0.4370	17.58		
23-Apr-92	10	4.0	34T		0.0216	2.16		0.26
22-Apr-92	11	20.0	19T		0.4316	22.66		
24-Apr-92	12	1.0	37T		0.0162	0.46		
24-Apr-92	13	5.0	38T	8.09E-03	0.7553	5.13		0.54
22-Apr-92	14	12.0	18T		1.6833	8.42		
22-Apr-92	15	30.0	14T		1.7804	19.10		1.62
21-Apr-92	16	24.0	17T		1.1654	47.39	9.323	
24-Apr-92	17	2.0	35T		0.0540	2.70	0.917	
24-Apr-92	18	5.8	39T	6.30E-03	0.0630	11.97	2.899	0.32
21-Apr-92	19	104.0	20T		12.9052	196.38	32.544	
21-Apr-92	20		09T					
21-Apr-92	21	222.0	24T					
20-Apr-92	22	30.0	15T		0.1619	66.36	10.521	1.62
20-Apr-92	23	4.8	30T		0.9562	6.98	1.396	0.26
20-Apr-92	24	717.0	12T	7.74E-01	54.1565	967.08		96.71
20-Apr-92	25	112.0	25T		25.9830	374.64	71.302	9.06

Table 4.—Loads of selected metals and arsenic at sites sampled during July 1992 in the Dolores River Basin

				Contaminant loadings				
Date		Ft^3/s	Site	Hg-load (lb/d)	As-load (lb/d)	Fe-load (lb/d)	Mn-load (lb/d)	Zn-load (lb/d)
13-Jul-92	T2	1.0	04T		0.0162	1.01	0.437	
13-Jul-92	T2	45.9	05T		1.4845		16.577	8.91
14-Jul-92	T2	0.0	16T		0.0010	0.03	0.011	
13-Jul-92	T2	32.1	21T		2.2535	46.46		4.16
13-Jul-92	T2	0.0	22T					
13-Jul-92	T2	2.4	23T		0.2708	5.33	1.251	0.19
13-Jul-92	T2	0.0	26T					
13-Jul-92	T2	11.1	40T		0.2989			1.20
13-Jul-92	T2	21.1	41T		0.4543			2.61
14-Jul-92	T2	6.0	42T		0.0966		4.831	
14-Jul-92	T2	5.9	43T		0.1581			
15-Jul-92	1	47.8	02T		3.0921	19.33	25.252	
15-Jul-92	2	9.7	01T		0.6280	3.19	3.035	0.73
15-Jul-92	3	3.7	31T		0.2954	5.57	1.319	0.24
14-Jul-92	4	0.0	29T	6.47E-06	0.0014	0.09	0.021	0.00
15-Jul-92	5	0.0	03T					
16-Jul-92	6	5.3	32T		0.5948	4.56	2.153	0.76
14-Jul-92	7	67.8	11T		2.1944	80.10	27.796	9.51
14-Jul-92	8	5.8	10T	6.20E-03	0.6204	17.65	4.591	4.62
14-Jul-92	9	0.0	28T	6.47E-06	0.0013	0.07	0.016	0.00
16-Jul-92	10	1.0	44T	1.08E-03	0.0270		0.669	
14-Jul-92	11	102.7	06T		2.2155	64.25	55.387	24.37
16-Jul-92	12	5.7	07T		0.3697	2.31	3.019	
15-Jul-92	13	95.4	08T	1.03E-01	6.6911	107.06	49.926	73.09
16-Jul-92	14	1.5	13T		0.0738	2.74	0.541	0.11
16-Jul-92	15	1.0	34T		0.0162	0.78	0.281	0.06
16-Jul-92	16	5.8	19T		0.1247	6.80		0.59
16-Jul-92	17	0.1	37T		0.0009	0.02	0.021	
16-Jul-92	18	0.1	36T		0.0006	0.02		
16-Jul-92	19	0.7	38T	1.18E-03	0.0906	0.69	0.228	0.06
16-Jul-92	20	2.1	18T		0.2391	3.14	0.763	
17-Jul-92	21	27.1	14T		1.3164	18.14		1.61
17-Jul-92	22	1.0	17T		0.0432	2.02	0.437	
15-Jul-92	23	5.9	20T		0.7346	11.88	1.852	0.64
15-Jul-92	24	0.0	09T					
14-Jul-92	24	100.0	24T		1.6182	83.61	99.790	
17-Jul-92	25	0.0	15T		0.0001	0.01	0.003	0.00
17-Jul-92	26	0.0	30T		0.0015	0.01	0.002	0.00
17-Jul-92	27	1.2	45T		0.1502	1.39	0.444	0.09
15-Jul-92	28	262.0	12T	2.83E-01	19.7894	305.32	81.985	32.51
17-Jul-92	29	1.0	25T	1.35E-03	0.2212	3.67	0.707	0.09

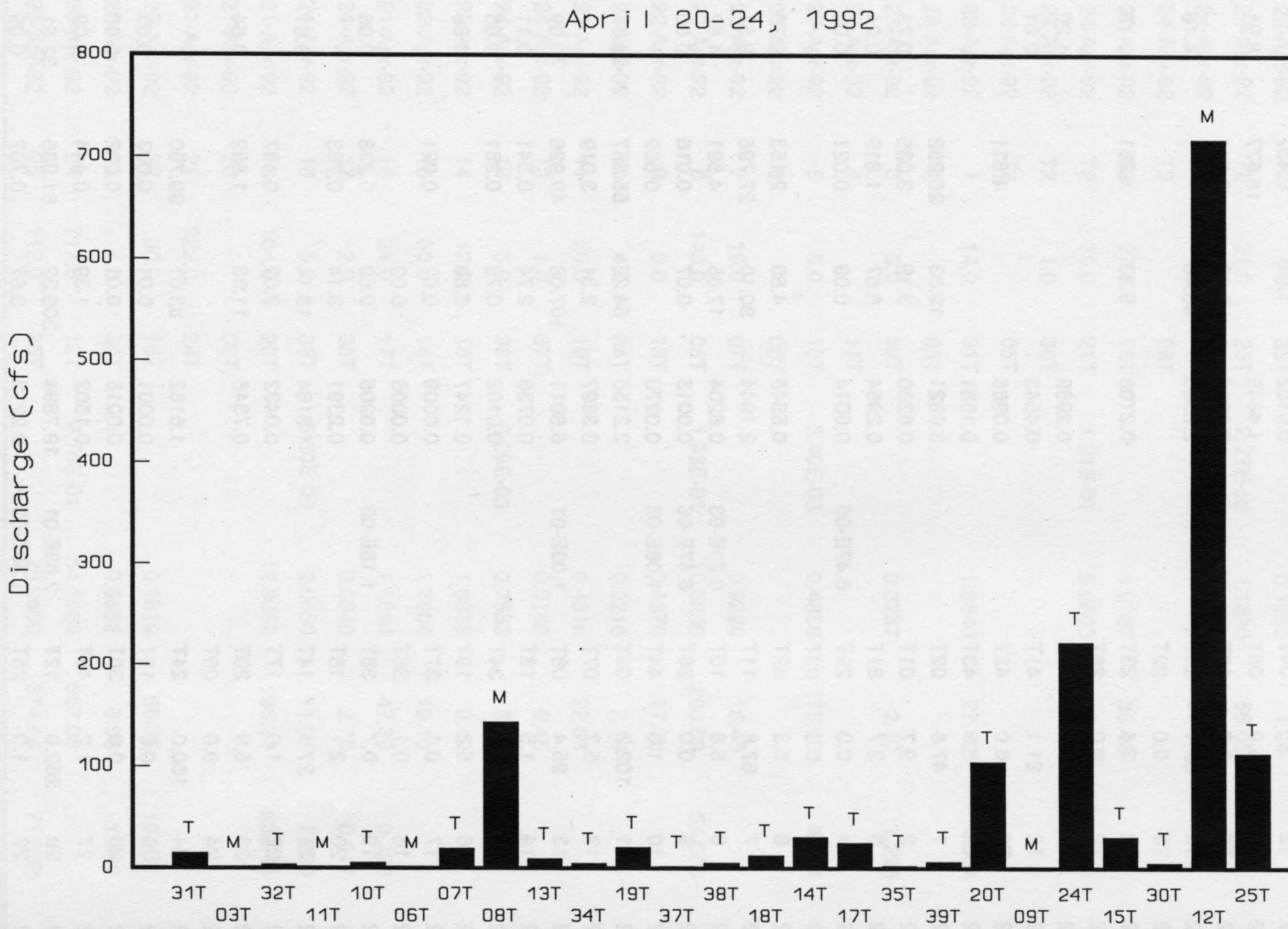

Figure 10.—Discharge of the Dolores River (M) and selected tributaries (T) at the time of water quality sampling during April 1992.

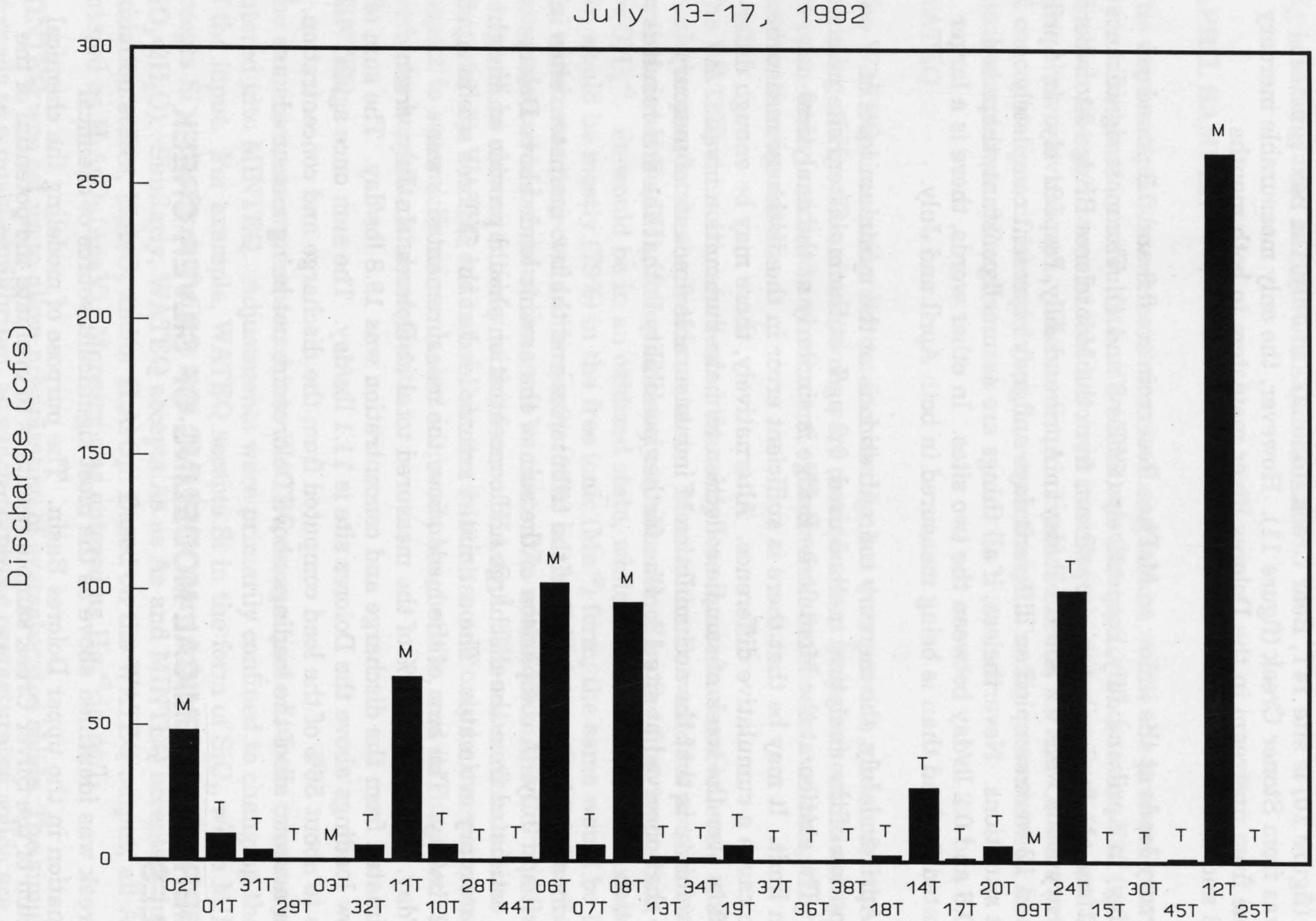

Figure 11.—Discharge of the Dolores River (M) and selected tributaries (T) at the time of water quality sampling during July 1992.

The inflow to McPhee Reservoir (site 12T) was much greater in April than in July (figures 10 and 11). The flow of Lost Canyon Creek was also much greater in April than in July at 112 versus 1 ft^3/s, respectively. In both April and July, the greatest inflow of any tributary is from the West Dolores River, which had a flow of about the same magnitude as the mainstem at site 8, the Montelores Bridge in April and only slightly less in July (figures 10 and 11). The next most significant tributary in April (figure 10) is site 14T, Bear Creek (table 2). In July, the next greatest inflow was from Stoner Creek (figure 11). However, the only measurable mercury load came from upstream in the Dolores River mainstem in both months (tables 3 and 4).

The mercury loads at the inflow to McPhee Reservoir are 0.8 and 0.3 pound per day (lb/day) in April and July, respectively (tables 3 and 4). The most significant contributions are from tributaries upstream from the Montelores Bridge site where the mercury loads were 0.2 and 0.1 lb/day in April and July, respectively. In April, sites 8 and 12 were sampled on different days and may represent completely different situations. Nevertheless, if all things are assumed constant, there is a gain of 0.6 and 0.2 lb/day between the two sites. In other words, there is a larger unaccounted for load than is being measured in both April and July.

In both April and July, the mercury concentration is at the minimum level of determination of the analytical method used, 0.2 µg/L at the mainstem site near Dolores. The station at the Montelores Bridge is similarly at the analytical detection limit. It may be that there is sufficient error in the discharge measurements to cause a cumulative difference. Alternatively, there may be enough difference in flow over the week of sample collection to make summation invalid. A third possibility is that the accumulation of immeasurable amounts of mercury totals to that observed at site 12. One further possibility is that the end result is a combination of the above.

There is measurable arsenic at all of the tributaries and the two mainstem sites in both April and July. A comparison of the sum of the arsenic loads above Dolores to the load estimated from the discharge and concentration should provide an insight into the mercury estimates. The estimated arsenic load at the Dolores site in April was 54.2 lbs/day. The sum of the loads above the measurement site was 30.5 lbs/day. The sum is 56% of the measured total at Dolores. In July, arsenic load estimated from the discharge and concentration was 19.8 lbs/day. The sum of the inflow loadings above the Dolores site is 11.1 lbs/day. The sum once again amounts to about 56% of the load computed from the discharge and concentration. Based on arsenic, all of the loadings above Dolores are not being measured.

EQUILIBRIUM CHEMICAL MODELING OF SILVER CREEK SAMPLES

Silver Creek was identified above as the most significant source of chemical contamination in the upper Dolores Basin. The purpose of modeling the chemical equilibrium of the Silver Creek sample results is to evaluate the potential of the various contaminants to travel to McPhee Reservoir without undergoing chemical reactions that could affect the solubility of the contaminants in transit. In the case of most of the metals, precipitation and loss to the sediments would be the primary mechanism. In the case of mercury, volatilization is also a possibility.

Simulations were undertaken using the USGS chemical equilibrium code, WATEQ, and the EPA code, MINTEQ. The MINTEQ simulations were undertaken because Hg is not included in the WATEQ database.

APRIL SAMPLE

The dominant cations were calcium and magnesium, while the predominant anions were bicarbonate and sulfate. The TDS was 264 mg/L. There were 580 µg/L of Fe, of which 164 µg/L were in the dissolved (nonfilterable) state. Both Mn and Zn were shown at 165 µg/L. The more toxic trace elements, As and Cd were present at concentrations of 18 and 1.5 µg/L, respectively. The Hg concentration in the April sample was 0.2 µg/L.

WATEQ

The WATEQ simulation did not include Hg, but does provide a basis for the modeling of Hg. The simulations were carried out at projected conditions typical of an open-water, oxidized environment. Where field data were available, they were used in the simulations.

The WATEQ simulation indicated that only less than measurable levels of Fe would be present in the free ionic state. Most of the Fe would be present as undissociated $Fe(OH)_3$, followed closely in abundance by the first ionization, $Fe(OH)_2^{+1}$. Fe would be in an oxidized state, while Mn would be more reduced. Mn would be mostly (79%) in the free ionic (Mn^{+2}) form; the same would be true of Zn, which was projected to be mostly (67%) in the Zn^{+2} form. The Cd distribution was projected to be about the same as that of Zn with 65% in the Cd^{+2} species. As would be almost entirely in the form of $HAsO_4^{-2}$. The saturation indices computed by WATEQ indicated that the solution would only be oversaturated with respect to several Fe minerals, but in particular goethite, and its diagenetic products, hematite and magnetite.

MINTEQ

The same data as were entered into WATEQ were adjusted where necessary and entered into MINTEQ. Adjustments were primarily confined to changing the form of the input. For example, WATEQ accepts Si in the form of SiO_2, while MINTEQ accepts Si in the form of silicic acid, H_4SiO_4 (or more accurately, hydrated silica, $SiO_2{\bullet}2H_2O$). Similarly, WATEQ accepts As as As and MINTEQ accepts it in the oxidation states, H_3AsO_3 and/or H_3AsO_4. Based on the WATEQ output, all As was entered as H_3AsO_4 (As+V). Mercury was entered as Hg_2^{+2} in µg/L.

MINTEQ was set up to allow precipitation of oversaturated solids. The simulation proceeds to a quasi-equilibrium, at which point the oversaturated solids are precipitated and the calculations are again undertaken on the basis of the updated concentrations of dissolved constituents. Unlike WATEQ, the final saturation indices will all be negative, indicating that all species are undersaturated. The projected amount of precipitate is estimated. Gaseous forms are also estimated. However, they were excluded from the simulations conducted in this study because there was no information on gas pressures over the solutions. Furthermore, the samples were collected from a relatively turbulent site, and gas pressures would be constantly changing.

The initial MINTEQ estimate indicated that potentially all Hg would be in the unionized form, Hg(aq). Potentially all could be in the gaseous form, Hg(g). If this were true, the potential for Hg transport would be limited. Hg loss in transit would be expected. On this basis, increases in Hg in the Dolores River should reflect additional loadings. Conceivably, the loadings could come from sediments making source identification extremely difficult.

MINTEQ projected that Fe, Mn and Zn would all precipitate before equilibrium would be achieved. The Fe and Mn would each precipitate as their oxides (hematite and manganite). Fe and Mn precipitation would amount to 100 percent of the total present. In other words, all Fe and Mn would be expected to be present as particulates, in which case the filtered sample would represent the concentration of unconsolidated molecules small enough to pass through the filter. The Zn would precipitate as the silicate, but less than 40% would be in the particulate form. However, due to the constantly changing conditions in a flowing-water environment, equilibrium is unlikely to ever be achieved.

JULY SAMPLE

The flow of Silver Creek was only slightly greater in July than it had been during April. The TDS was somewhat lower at 176 mg/L than had been observed in April. Trace element concentrations were similar in the 2 months. In July, there were 569 µg/L of Fe, 148 µg/L of Mn, and 149 µg/L of Zn. As and Cd were at 20 and 1.3 µg/L, respectively. The Hg concentration was the same as it had been in April at the minimum detectable concentration of 0.2 µg/L.

WATEQ

As was the case with the April sample, the July WATEQ results indicate that there should be no free ionic Fe. The Fe was projected to be present as nearly equal amounts of $Fe(OH)_3^{+1}$ and unionized $Fe(OH)_3$. Approximately 75% of the Zn and Cd were projected to be present in the free-ionic state (Zn^{+2} and Cd^{+2} respectively). On this basis, the results from July are very much like those of April. The list of oversaturated minerals and the degree to which they are oversaturated are also the same as in April.

MINTEQ

The similarity of the solutions with identical Hg concentrations would lead to the expectation that the MINTEQ results like the WATEQ results for the July sample would resemble the April sample. In April, MINTEQ took 32 iterations to equilibrate; in July, it took 34. The only difference in the precipitates in the 2 months was the additional loss of otavite ($CdCO_3$) from the July sample. Once again, an estimated 100% of the Fe and Mn would precipitate. The Zn and Cd precipitates would amount to 72 and 14% of their initial concentrations, respectively. Precipitated anions would comprise silicate and carbonate, but the predominant precipitated anion would be oxygen, probably initially as hydroxides with subsequent diagenesis leading to the formation of oxide minerals.

Gaseous mercury was projected to be identical to that of the April sample. However, gaseous mercury was not being specifically modeled, and the estimate of its gas phase is presumably based strictly on thermodynamics independent of the problem as defined for this MINTEQ application. In other words, the amount Hg(g) would not represent an equilibrium concentration in the final solution, but rather the amount that could be present due to the reduction-oridation potential (Eh) and pH of the initial sample. This becomes evident from the potential concentration of 0.8 µg/L ($4.3 \cdot 10^{-9}$ equivalents per liter [eq/L]), which is somewhat greater than the initial concentration in the sample.

The Hg data for the Dolores River show increases and decreases from upstream to downstream. The decrease may be due to dilution or Hg loss, e.g., volatilization, although the mechanism is not important in the context of this study. The increases can only be due to additional loadings or sources. Numerous potential sources have been identified during the study. If the decreases do actually represent losses, then any effects in McPhee Reservoir would have to be do to more local sources. Mercury that originated from more distant sources would not contribute because Hg losses in transit would prevent it from being carried all the way to the reservoir. Based on the samples collected during the study, the most significant source of mercury for fish in McPhee Reservoir may even be downstream from the Dolores River site at Dolores.

COMPARISON TO WATER QUALITY STANDARDS

Water quality standards for the Dolores River are reach specific. The Water Quality Commission, Colorado Department of Health, has classified the river into 11 reaches. All the reaches except reach 1 and reach 6 are included into the Dolores River Basin Water Quality Study (figure 1). Three of the reaches are located on the mainstem, and the remaining six are on tributaries. Standards are based on either acute or chronic aquatic life criteria. Most are based on the chronic criteria. For the most part, acute criteria apply only when there is no standard based on the chronic criteria. There are a few instances where both are applied.

In some cases, the Colorado Department of Health specifies the use of table value standards for contaminants (all metals) such as Cu, Ag, Cd, and Zn. Those standards are presented in the form of regression equations with the predetermined hardness level as the independent variable. In Colorado, the hardness-based standards use the upper bound of the 95 percent confidence interval of the long-term hardness distribution. However, there are no long-term hardness data available for the reaches in this study. Consequently, direct comparison to standards is not possible. In lieu of actual standards, estimated standards have been used. The estimates are based on instantaneous hardness data. Appendix B shows the water quality standards, both actual (nonhardness based) and estimated (hardness based), for the Dolores River above McPhee Reservoir that have been used in the study. Appendix C presents the results of comparisons to chronic water quality standards. Any sample that exceeds the resulting computed value has also been flagged with an asterisk, but should not be interpreted as exceeding a standard. Further evaluation would be necessary to draw such a conclusion. The flagged observations represent times and contaminants that are of greatest concern in the Dolores River basin based on the comparisons of concentrations with their respective chronic standards.

The comparison of the water quality data with levels representing those of the standards can be summarized as follows:

Reach 1: Reach 1 includes all tributaries to the Dolores River and West Dolores River, including all tributaries, lakes, and reservoirs, which are within the Lizard Head Wilderness. Water quality samples were not collected in this reach.

Reach 2: Reach 2 includes the mainstem of the Dolores River from its source to a point immediately above the confluence with Horse Creek. The July and September samples collected in 1990 show elevated levels of Hg (0.20 µg/L) in the Dolores River above Barlow Creek (site 02T). Samples were not collected in 1992.

Reach 3: Reach 3 includes the mainstem of the Dolores River from a point immediately above its confluence with Horse Creek to a point immediately above its confluence with Bear Creek. The samples collected in April and July 1992 show elevated levels of Hg in the vicinity of the Montelores Bridge (site 8T). The total and dissolved Hg concentrations at the site were both 0.25 µg/L.

Reach 4: Reach 4 includes the mainstem of the Dolores River from a point immediately above its confluence with Bear Creek to the bridge at Bradfield Ranch (Forest Route 505). The samples collected in April and July 1992 show elevated levels of total and dissolved Hg (0.20 µg/L) at the site near Dolores (site 12T).

Reach 5: Reach 5 includes all tributaries to the Dolores River and West Dolores River, including all lakes and reservoirs, from their source to a point immediately below the confluence with the West Dolores River except for specific listings included in reach 1 and reaches 6 through 10; the mainstem of Beaver Creek (including Plateau Creek) from its source to its confluence with the Dolores River. The July 1992 samples show elevated levels of Cu, Hg, Se, Ag, Zn, Mn, Pb, and Ni at the mine drain below Silver Creek (site 28T) and at the mine drain near the Peterson slide (site 29T), respectively. These sites have the highest concentrations of total and dissolved As of all the sampled sites.

Reach 6: Reach 6 includes the mainstem of the Slate Creek and Coke Oven Creek, from their sources to their confluences with the Dolores River. Water quality samples were not collected in this reach.

Reach 7: Reach 7 includes the mainstem of Coal Creek from its source to the confluence with the Dolores River. The samples do not indicate that there should be any major concern due to metals.

Reach 8: Reach 8 includes the mainstem of Horse Creek from its source to its confluence with the Dolores River. The sample results at site 32T within the reach do not show any major contamination due to metals.

Reach 9: Reach 9 includes the mainstem of Silver Creek from a point immediately below the town of Rico's water supply diversion to the confluence with the Dolores River. Samples collected in April and July 1992 show elevated levels of Cu, Hg, and Ag in Silver Creek near its mouth (site 10T).

Reach 10: Reach 10 includes the mainstem of the West Dolores River from its source to its confluence with the Dolores River. The samples collected at sites 05T, 24T, and 26T in the reach do not indicate any major contamination due to metals.

Reach 11: Reach 11 includes all tributaries to the Dolores River, including all lakes and reservoirs, from a point immediately below the confluence of the West Dolores River, to the bridge at Bradfield Ranch (Forest Route 505), except for the specific listing in reach 5. The samples in the reach do not indicate that there is any major contamination due to metals.

SEDIMENT

The results from sediment sampling conducted during 1989 seem much more definitive than those of the water samples. The mercury concentrations in the sediments during September 1989 are shown on figure 12. There is detectable mercury in all 1989 samples shown on the figure, including the most upstream site. It should be noted, however, that the mercury determination that was performed is similar to an assay on rocks or mineral deposits and in no way represents a soluble or bioavailable form of mercury. Nevertheless, the higher mercury concentrations are observed near sites with potential sources of mercury. The highest sediment mercury concentration is at site D-5, which is located in Silver Creek near its mouth.

The peak mercury in the sediments of the mainstem of the Dolores River was observed at site D-6. If the source of the sediment containing the high mercury concentration were Silver Creek, the peak mercury in the river sediments would be expected nearer the Silver Creek confluence at site D-4. However, the depositional area for the Silver Creek sediments will vary from year to year and flood to flood depending on the capability of the Dolores River to suspend the sediment following its introduction into the river or the time available to either resuspend the

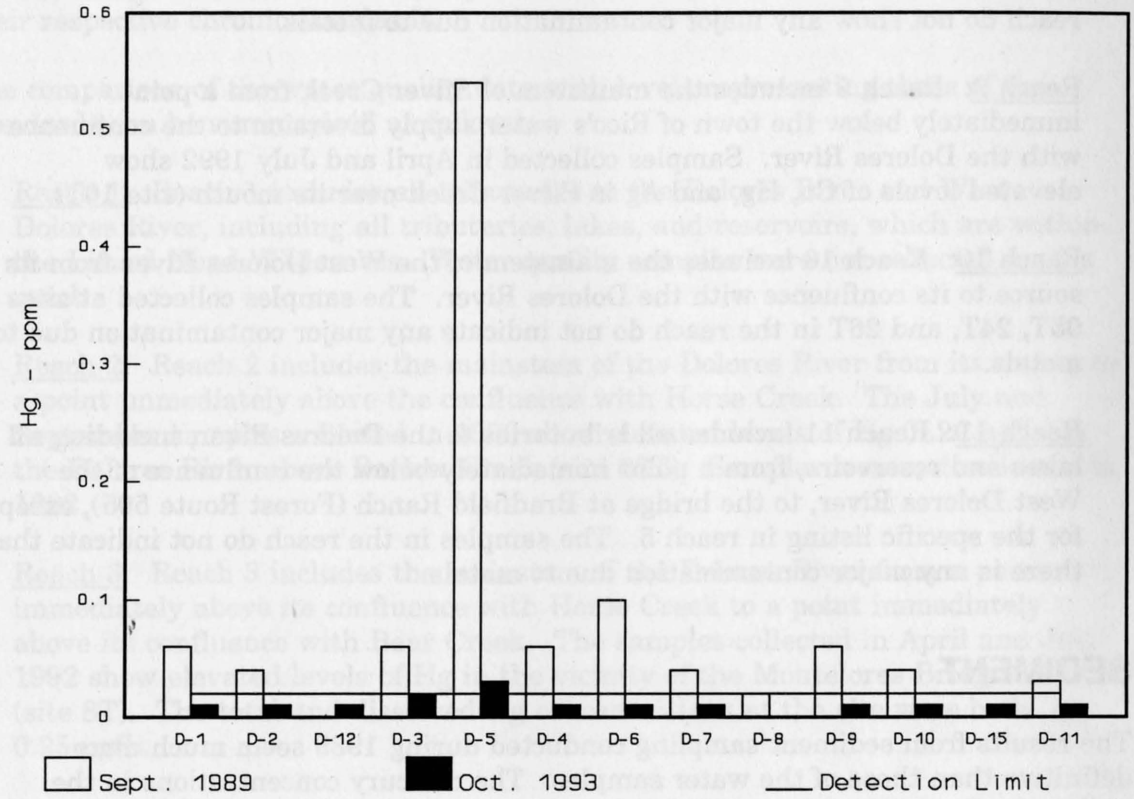

Figure 12.—Mercury concentrations in the Dolores River sediments during 1989 and 1993.

sediment or to move it as part of the river's bedload. Consequently, the principal depositional area for Silver Creek sediments may actually be nearer to site D-6 than D-4.

Because detectable mercury was observed at all sites sampled during 1989, the sampling was repeated during 1993. In addition, several sites were added. The 1993 sample results are also plotted on figure 12. There was observable mercury at only two sites sampled during 1993. The site just upstream from Rico (D-3), where the Hg concentration was at the minimum detectable concentration, and Silver Creek (D-5) were the only ones with measurable Hg (figure 12). This verifies the sources above Rico, but shows nothing in the lower basin. It appears that the runoff during the spring of 1993 was sufficient to both scour most of the river bed and transport most of the contaminated sediment beyond the boundaries of the study area.

Other heavy metals, Cd, Pb, Mn, and Zn, and the metalloid, As, also exhibit their highest concentrations in the 1989 samples at site D-5, as shown in figures 13 and 14. The contaminant that is the lone exception is Se, which is not necessarily associated with mining; Se peaks at site D-6. Of the trace elements other than mercury shown on the plots, all but Se show peaks in Silver Creek. The magnitude of the peaks in Silver Creek vary among the various trace elements. The resulting concentration in the river also shows considerable variation among the various trace elements. For example, As shows a peak in Silver Creek that is approximately twice the concentration of As in the Dolores River upstream from the creek (figure 13). The As concentration in the Dolores River downstream from Silver Creek is approximately the same as the upstream concentration (figure 13). Cadmium, on the other hand, is below a measurable concentration at the first two Dolores River sites. There are 2 ppm of Cd at the site upstream from Silver Creek. The Silver Creek sediments contain over 30 ppm of Cd. The site immediately downstream from Silver Creek (D-4) had 6 ppm of Cd in the sediments, a threefold increase over the upstream site. Cd subsequently showed a gradual decline to below detectable levels (<2 ppm) at the site just upstream from the West Dolores River (D-10) and remained at that level to the station just upstream from McPhee Reservoir (figure 13).

The heavy metals, Pb, Mn, and Zn, are at relatively low concentrations at the sites upstream from Silver Creek. Silver Creek itself shows extremely high concentrations of all three metals in its sediments (figure 14). All three metals remain at relatively high concentrations in the Dolores River sediments downstream from Silver Creek until the site near the mouth of the West Dolores River. The three metals in the sediments at the site near McPhee Reservoir are at about the same concentrations as those shown above Silver Creek (figure 14).

The 1989 sediment data show Silver Creek to be the major source of heavy metals, including mercury, in the upper Dolores River basin. There is an increase in the mercury concentration in the sediments between sites D-4 and D-6, indicating a possible second (or third) source, but there are no sediment data to indicate where such a source might be located. It should be noted that the differences in the mercury concentrations in the Dolores River sediments are small and may be

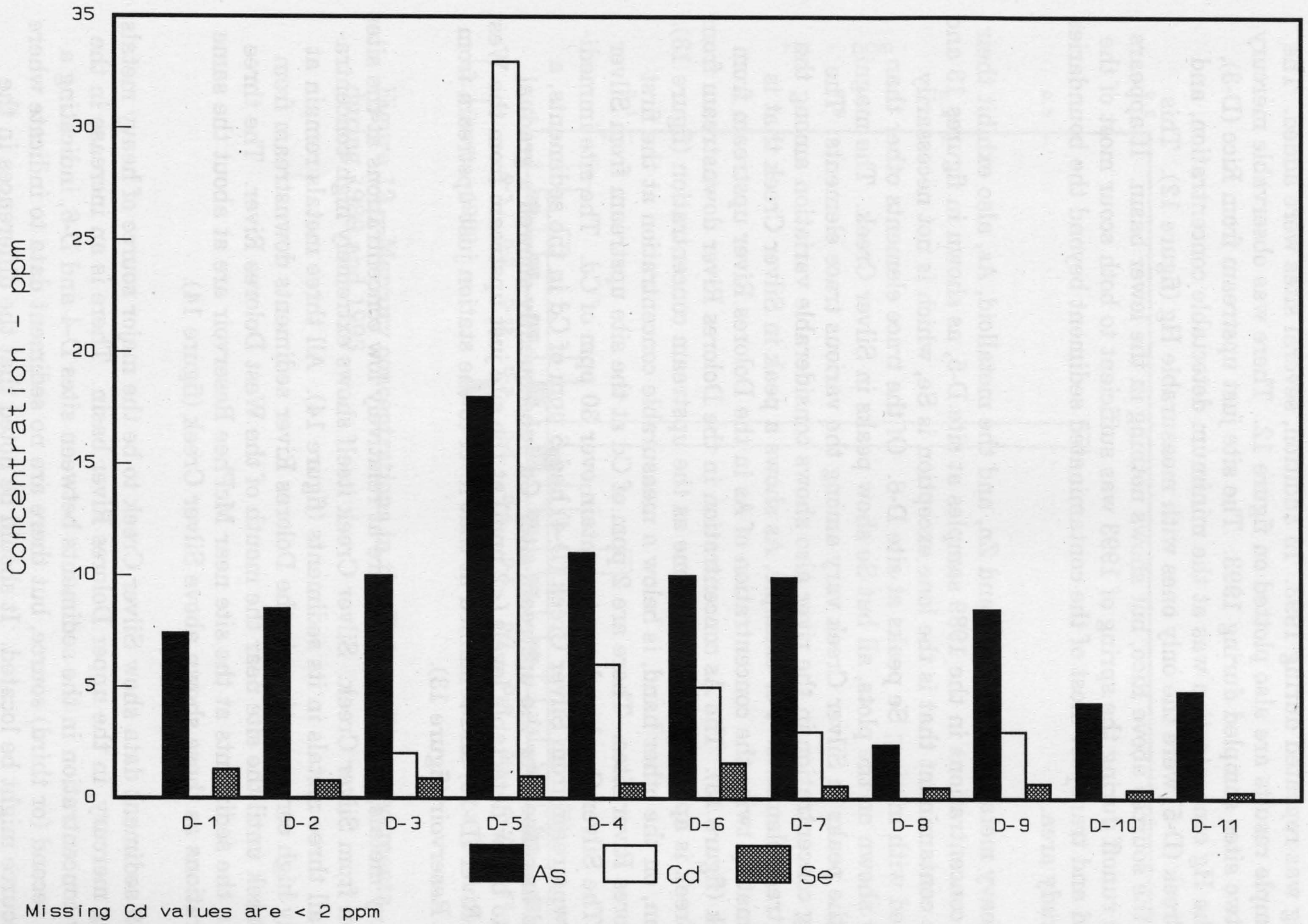

Figure 13.—Arsenic, cadmium, and selenium concentrations in the Dolores River sediments—September 17, 1989.

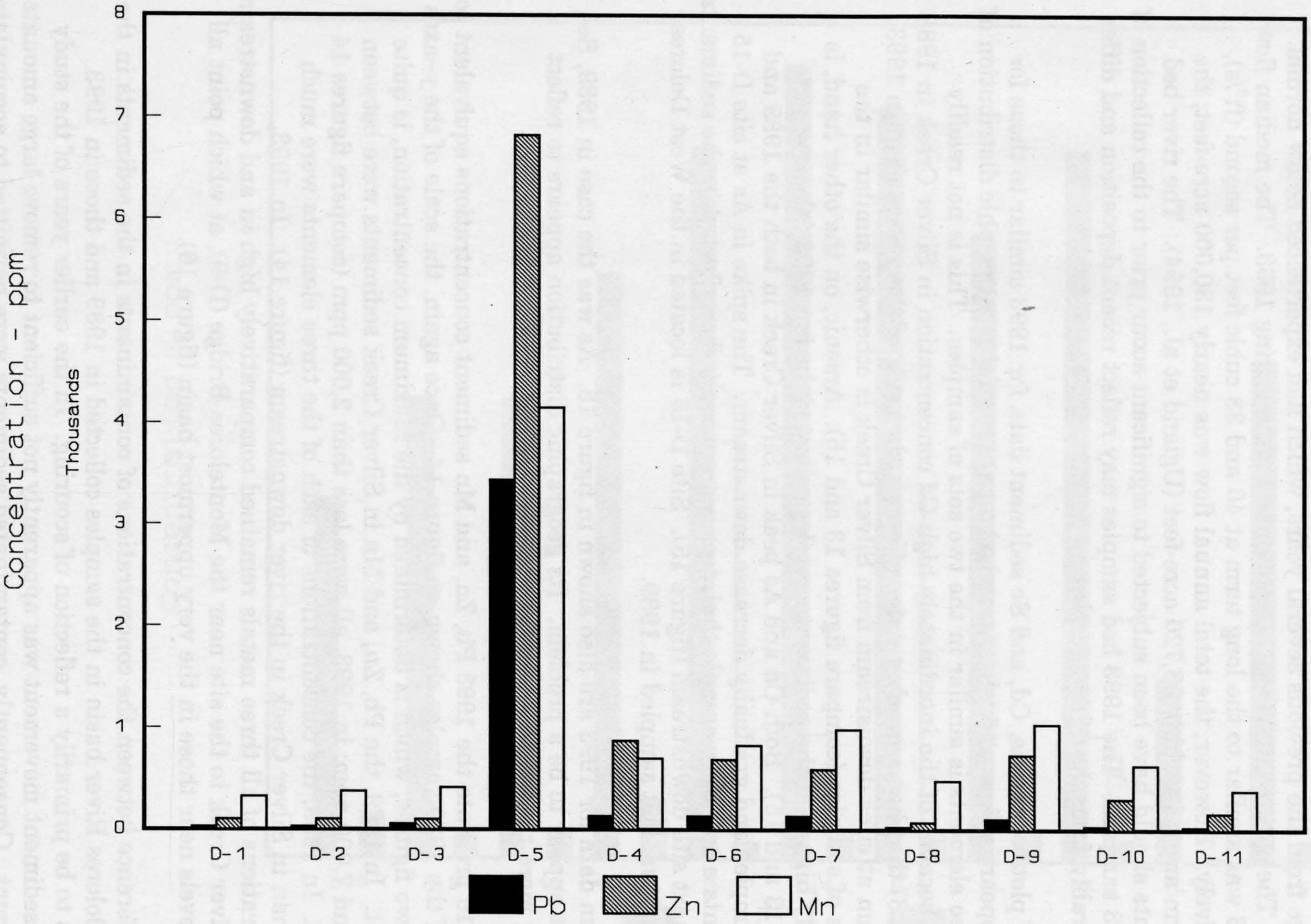

Figure 14.—Lead, zinc, and manganese concentrations in the Dolores River sediments—September 17, 1989.

nothing more than random variation. An indication that such may be the case is the fact that other contaminants in the sediments do not show the same pattern in the mainstem as mercury does.

Additional samples were collected during October 1993. Water year 1993 marked a change from the previous several years, which had experienced below normal runoff. The spring runoff was exceptionally large during 1993. The median flow for 1993 was similar to the long term at 40 and 38 cubic feet per second (ft^3/s), respectively. However, the total annual flow was nearly 130,000 acre-feet; the long-term annual yield is 98,720 acre-feet (Ugland et al., 1994). The river bed sediments should have been subjected to significant scour prior to the collection of the 1993 samples. The 1993 bed samples may reflect recent deposition and differ considerably from the 1989 samples.

A set of plots of the As, Cd, and Se sediment data for 1993 similar to those for 1989 appear in figure 15. In general, the pattern of the geographic distribution of the three elements is similar in the two sets of samples. This is not readily obvious because of the inordinately high Cd concentration in Silver Creek in 1989 (figure 13) that has a much greater effect on the scale of the *y*–axis than in 1993. Cadmium at sites downstream from Silver Creek is otherwise similar in the two sets of samples (compare figures 13 and 15). Arsenic, on the other hand, is generally higher in the sediment samples collected during 1993 (also compare figures 13 and 15). Both Cd and As peak in Silver Creek in both the 1989 and 1993 samples and gradually decrease downstream. The spike in As at site D-15 represents a tributary sample that does not appear to be reflected in the sediments at the next site downstream (figure 15). Site D-15 is located in the West Dolores River and was not sampled in 1989.

Selenium data for 1993 are also shown in figure 15. As was the case in 1989, Se does not appear to be a problem. Its geographic distribution appears to reflect nothing more than random variation.

Figure 16 presents the 1993 Pb, Zn, and Mn sediment concentrations equivalent to those of the 1989 samples shown on figure 14. Once again, the scale of the *y*–axes in the two figures, which is determined by the maximum concentration, is quite different. In 1989, the Pb, Zn, and Mn in Silver Creek sediments were between 3,000 and 7,000 ppm; in 1993, all were less than 2,000 ppm (compare figures 14 and 16). In 1989, the concentrations of each of the three elements were much lower than in Silver Creek in the river downstream (figure 14). In 1993, concentrations of all three metals remained comparatively high in and downstream from Silver Creek to the site near the Montelores Bridge (D-9), at which point all fell to levels near those in the very uppermost basin (figure 16).

The difference between the concentrations of contaminants in the sediments in the upper Dolores River basin in the samples collected in 1989 and those in 1993 appears to be primarily a reflection of scouring. In the earlier years of the study period, sediment movement was apparently not sufficient to remove large amounts of sediment. Consequently, contaminated sediments were permitted to accumulate. Sediments with the greatest concentration of heavy metals would have a greater density than those composed of lighter elements and would be expected to settle

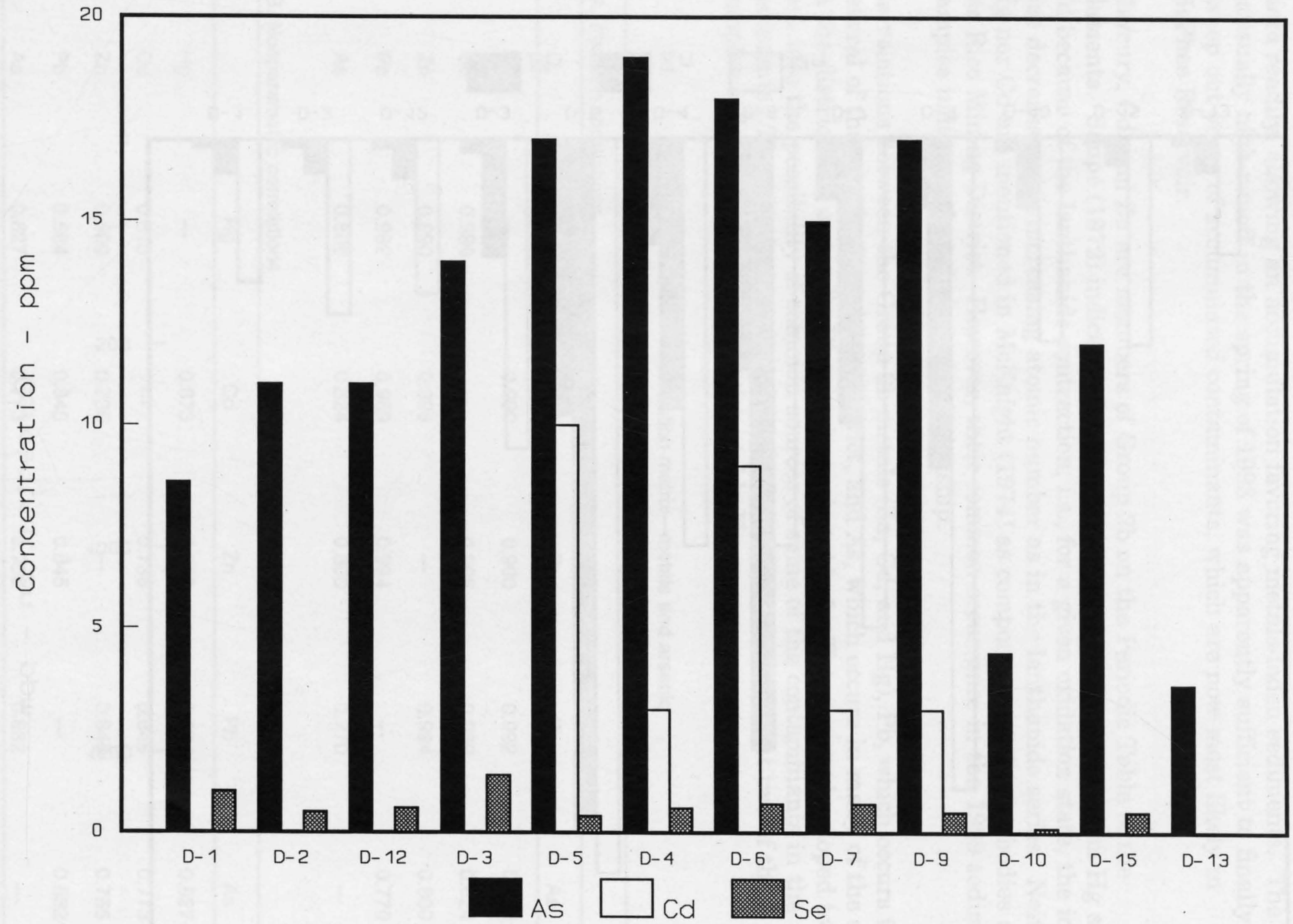

Figure 15.—Arsenic, cadmium, and selenium in the Dolores River sediments during October 1993.

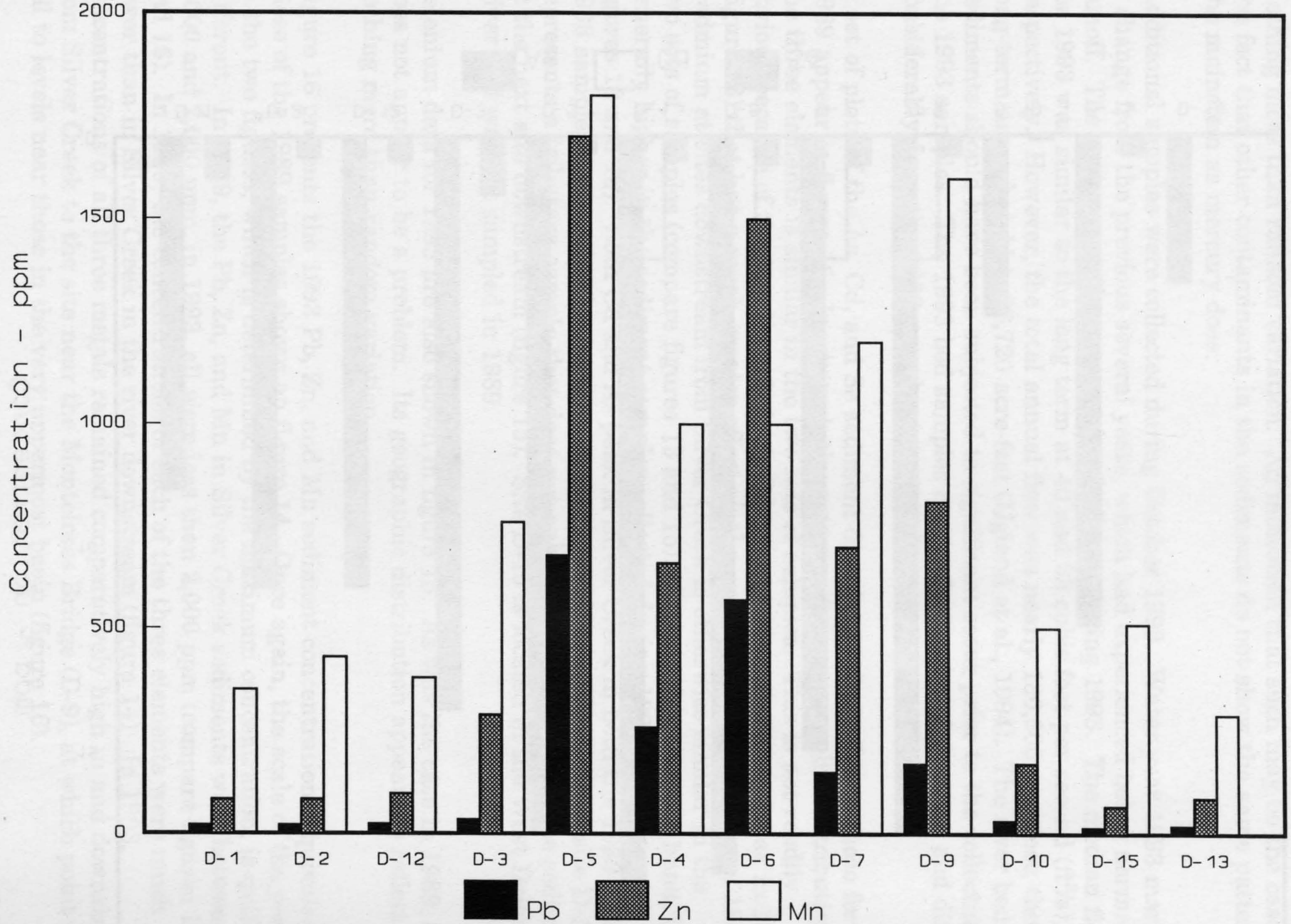

Figure 16.—Lead, zinc, and manganese in the Dolores River sediments during October 1993.

more readily, allowing an accumulation favoring metals-laden sediments. The unusually high runoff in the spring of 1993 was apparently sufficient to finally sweep out years of accumulated contaminants, which are now most likely in McPhee Reservoir.

Mercury, Cd, and Zn are members of Group 2b on the Periodic Table of the elements. Saupé (1972) indicates that there is a great similarity between Hg and Cd because of the lanthanide contraction; i.e., for a given oxidation state, the ionic size decreases with increasing atomic number as in the lanthanide series. Neither Hg nor Cd are mentioned in McKnight (1974) as components of the ore bodies of the Rico Mining District. However, their common occurrence in the 1989 sediment samples indicates that there is a relationship.

Correlations between the Group 2b metals (Zn, Cd, and Hg), Pb, which occurs in several of the ores in the mining district, and As, which occurs in many of the ores in the district (see appendix D), are shown in table 5. These were developed to look into the possibility of common sources of some of the contaminants in the sediments. The correlations include data for 1989 because all but two of the samples collected in 1993 had no detectable Hg.

Table 5.—Correlation matrix—metals and arsenic concentrations in Dolores River bed sediments

A. Pearson correlations

	Hg	Cd	Zn	Pb	As
Hg	---	0.990	0.990	0.992	0.806
Cd	0.990	---	0.996	0.989	0.824
Zn	0.990	0.996	---	0.994	0.800
Pb	0.992	0.989	0.994	---	0.770
As	0.806	0.824	0.800	0.770	---

B. Nonparametric correlations

	Hg	Cd	Zn	Pb	As
Hg	---	0.673	0.509	0.564	0.827
Cd	0.673	---	0.736	0.845	0.773
Zn	0.509	0.736	---	0.845	0.755
Pb	0.564	0.845	0.845	---	0.882
As	0.827	0.773	0.755	0.882	---

Note.—For 9 degrees of freedom: the r at $\alpha_{0.01}$ is 0.735 and the r at $\alpha_{0.05}$ is 0.602.

Table 5A shows extremely good correlations between all four of the metals. However, the correlations of the metals with As are not quite as good. Arsenic occurs in the mineralized area primarily as the As^{-2} anion (see appendix D). Its chemical behavior is much different from that of the metals. Consequently, even if the sources are the same, their behavior after they have entered the river may have a considerable effect on where, or if, accumulation occurs.

The concentration of most of the elements is much higher in the Silver Creek sediments than at any of the other sites. Such an overwhelmingly large set of high values can have a proportionally large effect on a correlation. To investigate the effect of the data pair from Silver Creek, the correlation between Hg and Zn was recomputed without the Silver Creek couple. The resulting correlation ($r = 0.52$) was not statistically significant. Based on this, a set of nonparametric correlations (based on rank vs. order) was computed. Such correlations weight each data pair equally, eliminating the disproportionate contribution to the sums of squares by the very large values of the Silver Creek pairs. The nonparametric correlations are summarized in table 5B.

When the influence of Silver Creek is normalized, Hg is significantly correlated only with Cd, its neighbor in Group 2b, and As. The correlations of Hg with Zn and Hg with Pb become nonsignificant (table 5B). All other correlations remain significant at least the 0.05 α–level. Arsenic remains highly significantly (probability <0.01) correlated with all of the metals. This indicates that the elements associated with mining in the Rico Mining District, with the exception of Hg, are influenced similarly in the river upstream from McPhee Reservoir.

Besides showing that the Silver Creek sample had a disproportionate effect on the correlation among contaminants, this exercise indicates that Silver Creek is a disproportionately large source of several contaminants. Although the data collected in this study indicate that there are numerous possible sources of Hg in the Dolores Basin, the most significant appears to be the Silver Creek basin. However, based on the difference in the two sets of correlations, the other sources are still significant to the distribution of Hg in the upper Dolores Basin.

CONTAMINANTS IN FISH AND AQUATIC INVERTEBRATES

At the time the sediment samples were collected in September 1989, fish and invertebrate samples were also collected. Chemical analyses were performed for As, Cd, Hg, Pb, Se, and Zn in samples collected at six of the sites. All analyses were performed on whole body samples. The sample sites and the sample compositions are summarized in table 6. Although the biological sample sites coincide with sediment sites, the numbers coincide with the original sediment sample site numbers.

Fish were collected by electroshocking. The invertebrate samples were collected with a kick screen. Samples were sorted into lots, the composition of which is described briefly in table 6. Samples were frozen and submitted for analysis to the Environmental Trace Substances Research Center, Columbia, Missouri.

The samples were chosen to represent different trophic levels. The base of the sampled food chain is represented by the invertebrates. However, there would be considerable overlap between sculpin and trout in the choice of food items. Both

Table 6.—Fish and invertebrates site locations and sample descriptions

Sample No.	Site No.	Station location	Date	Sample description (all whole body)
D2BT1	F-2	Dolores River 1/8 mile above Barlow Creek	09/19/89	1 brown trout
D3BT1	F-3	Dolores River 2.5 miles from Rico	09/19/89	1 brown trout
D3BT2	F-3	Dolores River 2.5 miles from Rico	09/19/89	5 brown trout
D4BT2	F-4	Dolores River at C145 bridge in Rico	09/19/89	4 brown trout
D7BT1	F-7	Dolores River below Rico at graveyard	09/20/89	1 brown trout
D10BT1	F-10	Dolores River at Montelores Bridge	09/20/89	3 brown trout
D11RT1	F-11	Dolores River above West Dolores River	09/20/89	1 rainbow trout
D2MS	F-2	Dolores River 1/8 mile above Barlow Creek	09/19/89	8 mottled sculpin
D3MS	F-3	Dolores River 2.5 miles from Rico	09/19/89	10 mottled sculpin
D4MS	F-4	Dolores River at C145 bridge in Rico	09/19/89	7 mottled sculpin
D7MS	F-7	Dolores River below Rico at graveyard	09/20/89	14 mottled sculpin
D10MS	F-10	Dolores River at Montelores Bridge	09/20/89	12 mottled sculpin
D11MS	F-11	Dolores River above West Dolores River	09/20/89	24 mottled sculpin
D2I	F-2	Dolores River 1/8 mile above Barlow Creek	09/19/89	1/2 oz macroinvertebrates
D3I	F-3	Dolores River 2.5 miles from Rico	09/19/89	5/8 oz macroinvertebrates
D4I	F-4	Dolores River at C145 bridge in Rico	09/19/89	5/8 oz macroinvertebrates
D7I	F-7	Dolores River below Rico at graveyard	09/20/89	1/2 oz macroinvertebrates
D10I	F-10	Dolores River at Montelores Bridge	09/20/89	3/4 oz macroinvertebrates
D11I	F-11	Dolores River above West Dolores River	09/20/89	1/2 oz macroinvertebrates

feed on aquatic invertebrates, but size selectivity would limit overlap to some extent. At maturity, sculpin would be much smaller than trout, and it is likely that trout are feeding on sculpin, particularly the larger trout, which are frequently piscivorous. However, in the type of habitat represented by the Dolores River, even the larger trout would be expected to feed extensively on aquatic and terrestrial invertebrates.

Silver Creek was devoid of macroscopic aquatic life. Therefore, no biological samples were collected there.

Mercury concentrations in the biological samples are shown in figure 17. The data presented in figure 17 appear to indicate significant bioaccumulation of Hg in the Dolores Basin upstream from McPhee Reservoir. However, unlike those in fish in the reservoir, all of the mercury concentrations in fish are well below levels of concern for human consumption. The basis for comparison presented in figure 17 is the 85th percentile of the Fish and Wildlife Service's National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990). The baseline is much lower than any guideline related to fish consumption by humans and should be indicative of an uncontaminated system.

The invertebrate samples show a virtually constant concentration of Hg at all six sites. The range is only from 0.008 ppm at the farthest downstream two sites to the maximum of 0.012 ppm at the site downstream from Rico. The headwaters site shows only slightly lower Hg in the invertebrate sample than that of the site below Rico with a Hg concentration of 0.01 ppm. The mercury in the invertebrate samples does not show any defined trend related to sample location, although the lowest Hg concentrations are in the samples from the farthest downstream sites. The invertebrate Hg seems to primarily represent random variation.

The sculpin results are somewhat similar to those of the invertebrates (figure 17). The most obvious difference from the distribution of Hg in the invertebrates is the peak in Hg in the sculpin at the site in Rico; the second highest Hg in the sculpin is at the farthest upstream site above Barlow Creek. The lowest Hg in sculpin was at the farthest downstream site, just as it was in the invertebrates (figure 17). The sculpin collected at the remaining three sites showed a similar Hg concentration, with a range from 0.23 to 0.26 ppm. However, the total range in Hg in all of the sculpin was between 0.17 and 0.39 ppm, which is still comparatively small.

The trout showed a generally increasing Hg concentration from upstream to downstream, although the actual minimum concentration was in the sample collected in Rico (figure 17). Based on the plotted trout data, there does appear to be some degree of Hg accumulation between the site above the historic mining activity and the site near the mouth of the West Dolores River. However, there are a couple of points that need to be considered.

The maximum Hg in the trout plot is from the sample collected farthest downstream in the vicinity of the West Dolores at site D-11. Although possibly of no importance, the sample collected at biological sample site D-11 was a rainbow trout, while all of the other trout samples consisted of browns (table 6). It should be noted that the trout sample with the actual maximum was in a sample collected

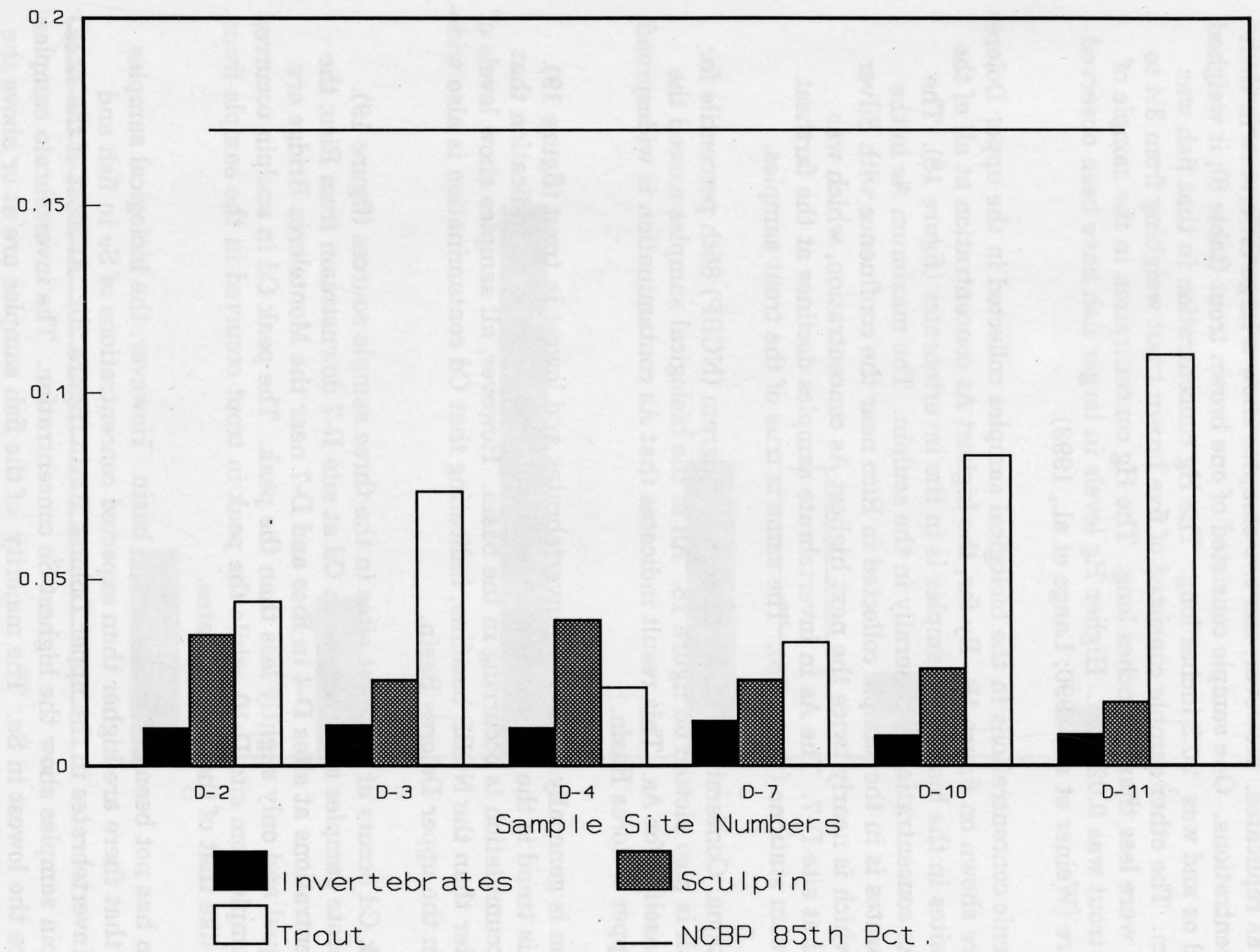

Figure 17.—Mercury concentrations in fish and invertebrate samples collected at six sites in the Dolores River during September 1989.

at site D-3. For plotting purposes the two samples collected at D-3 have been treated as replicates. However, the two samples show a large difference in their Hg concentrations. One sample consisted of one brown trout (table 6); it weighed 2 lbs, 13 oz and was 20.2 inches long. The Hg concentration in that fish was 0.13 ppm. The other sample consisted of five brown trout weighing from 3¼ to 4 oz; all were less than 12 inches long. The Hg concentration in the sample of smaller trout was 0.02 ppm. Higher Hg levels in larger fish have been observed elsewhere (Weiner et al., 1990; Lange et al., 1993).

The arsenic concentrations in the biological samples collected in the upper Dolores Basin are shown on figure 18. By far, the highest As concentration at all of the sample sites in the biological samples is in the invertebrates (figure 18). The lowest As concentration is generally in the sculpin. The maximum As in the invertebrates is in the sample collected in Rico near the confluence with Silver Creek, which is nearly twice the next highest As concentration, which was observed at site D-7. The As in invertebrate samples declines at the farthest downstream stations (figure 18). The same is true of the trout samples.

The National Contaminants Biomonitoring Program (NCBP) 85th percentile for As in fish is also plotted on figure 18. All of the biological samples exceed the NCBP baseline for As. This result indicates that As contamination is widespread in the upper Dolores Basin.

Cadmium is generally greatest in invertebrates and lowest in trout (figure 19). Since this trend is the antithesis of bioaccumulation, there is no indication that Cd bioaccumulation is occurring in the basin. However, all samples show levels of Cd greater than the NCBP baseline, indicating that Cd contamination is also widespread in the upper Dolores Basin.

The peak Cd occurs at different sites in the three sample sources (figure 19). Invertebrate samples show a peak in Cd at site D-7 downstream from Rico; the Cd concentrations at sites D-4 in Rico and D-7 near the Montelores Bridge are about equal and only slightly less than the peak. The peak Cd in sculpin occurred in the sample from site D-10, while the peak in trout occurred in the sample from site D-7 like that of the invertebrates.

Selenium has not been of concern in the basin. However, the biological samples indicate that there are higher than expected concentrations of Se in fish and aquatic invertebrates in the upper Dolores Basin (figure 20). At most of the sites, the sculpin samples show the highest Se concentration. The invertebrate samples tend to be the lowest in Se. The majority of the fish samples are at or above the NCBP baseline for Se (figure 20). Since the fish are higher in Se than the invertebrates, the possibility of bioaccumulation of Se in the basin cannot be ruled out. However, the data are insufficient to give a definitive answer.

Lead for the most part exhibits its highest concentrations in biological samples in the invertebrates (figure 21). The exception is the trout sample from site D-7, which has the peak Pb concentration of any of the biological samples collected during 1989. The trout samples from sites D-4, D-7, and D-10 exceed the NCBP baseline and indicate at least some degree of contamination.

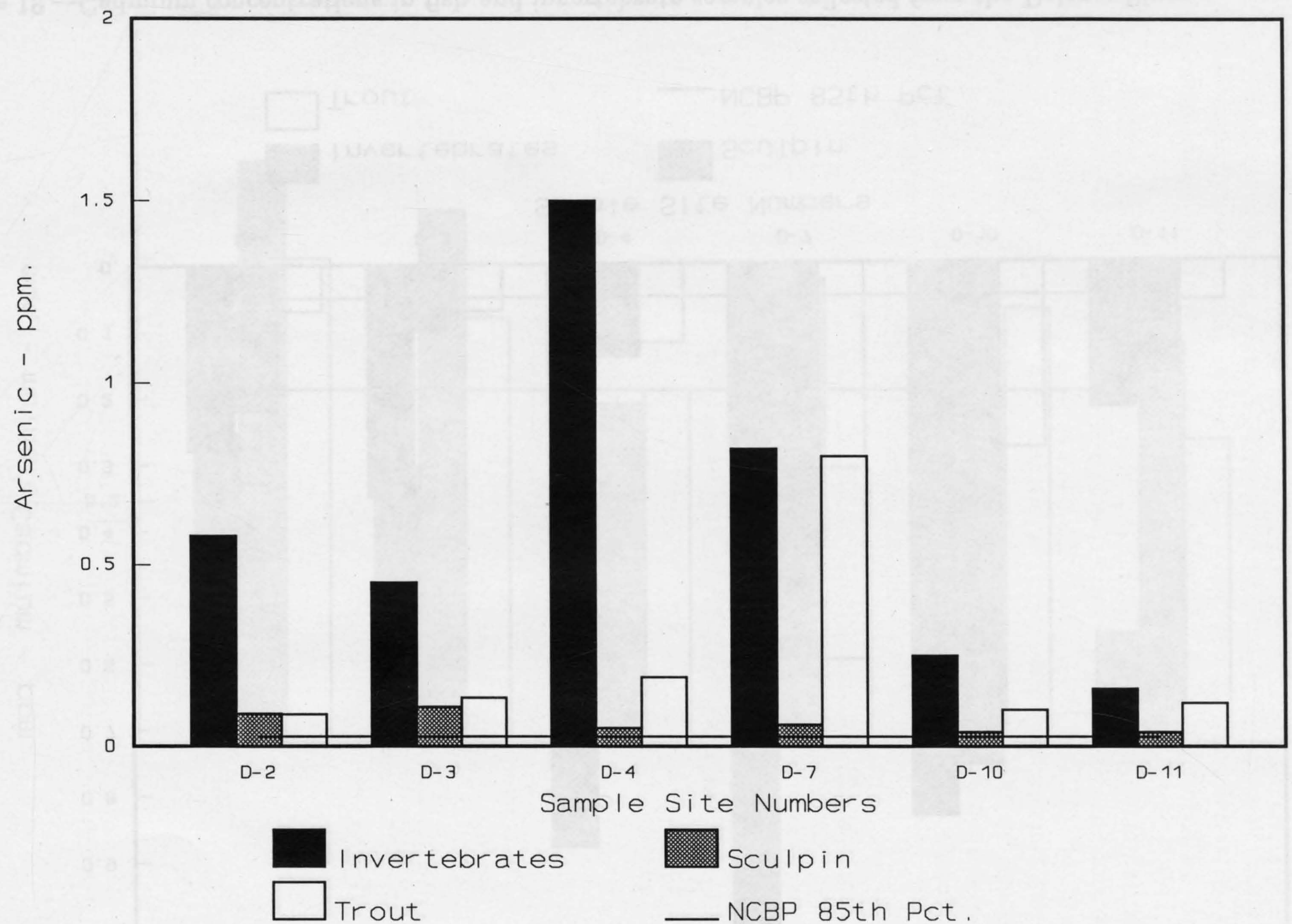

Figure 18.—Arsenic concentrations in fish and invertebrate samples collected from the Dolores River during September 1989.

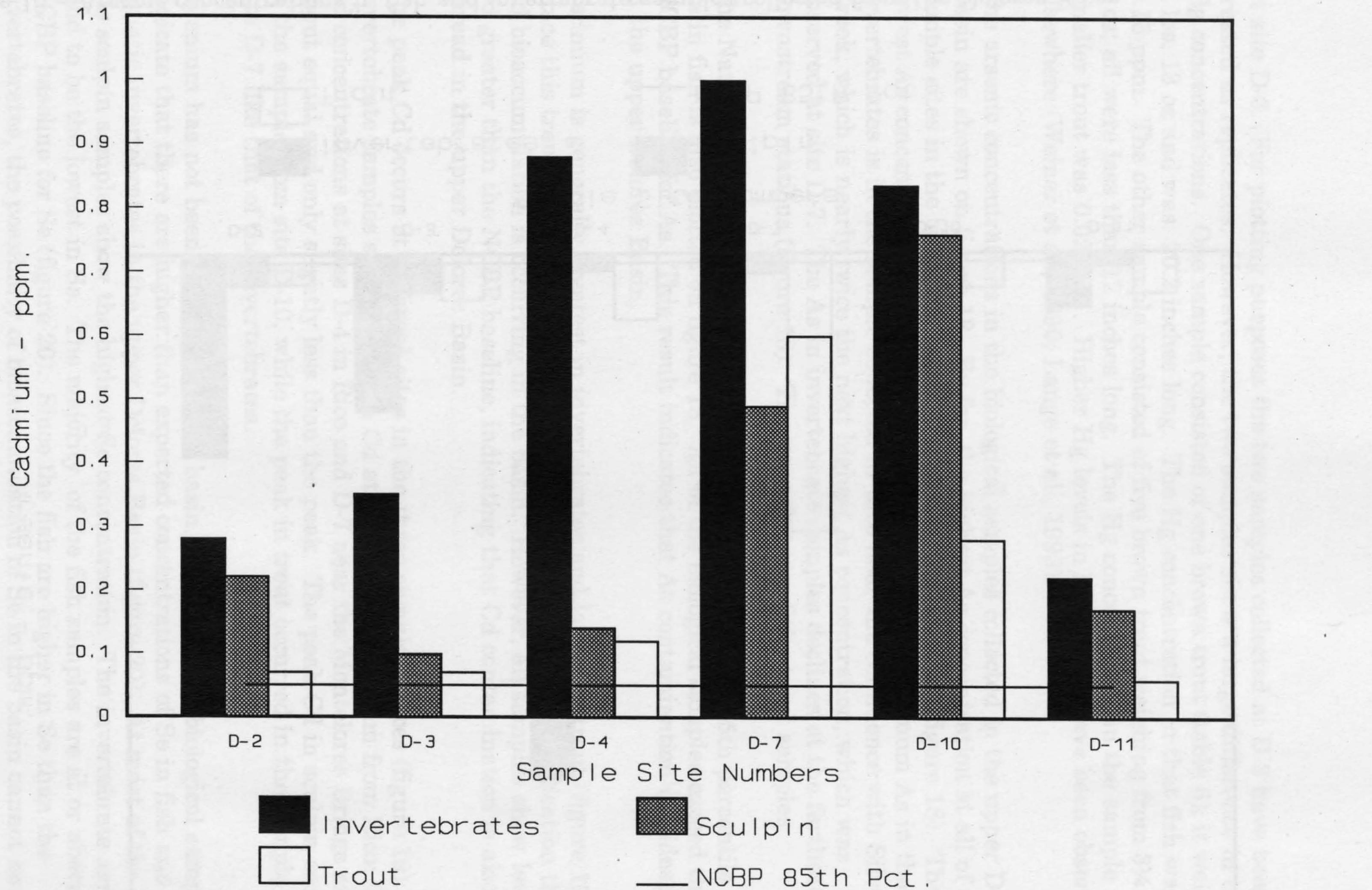

Figure 19.—Cadmium concentrations in fish and invertebrate samples collected from the Dolores River during September 1989.

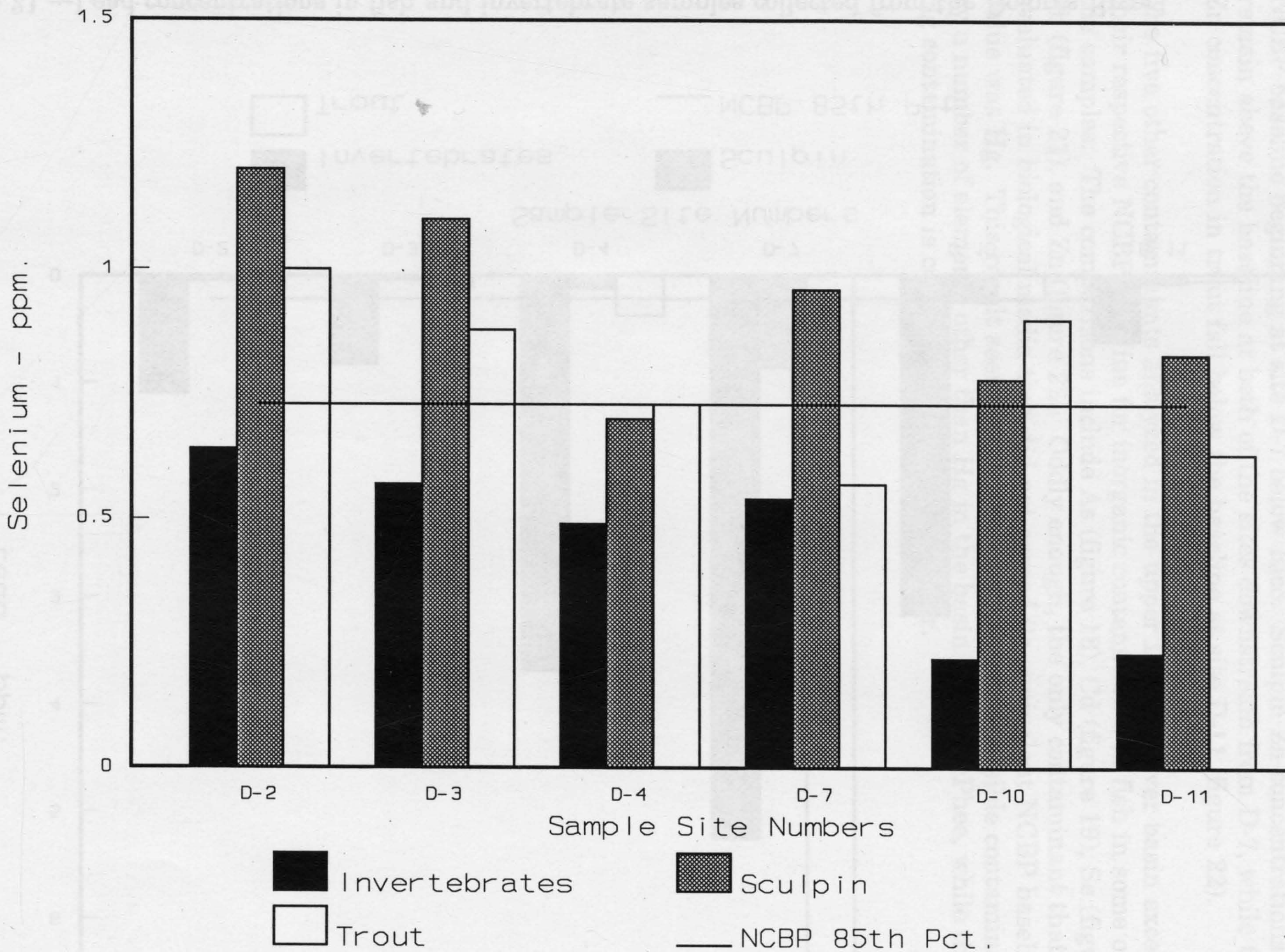

Figure 20.—Selenium concentrations in fish and invertebrate samples collected from the Dolores River in September 1989.

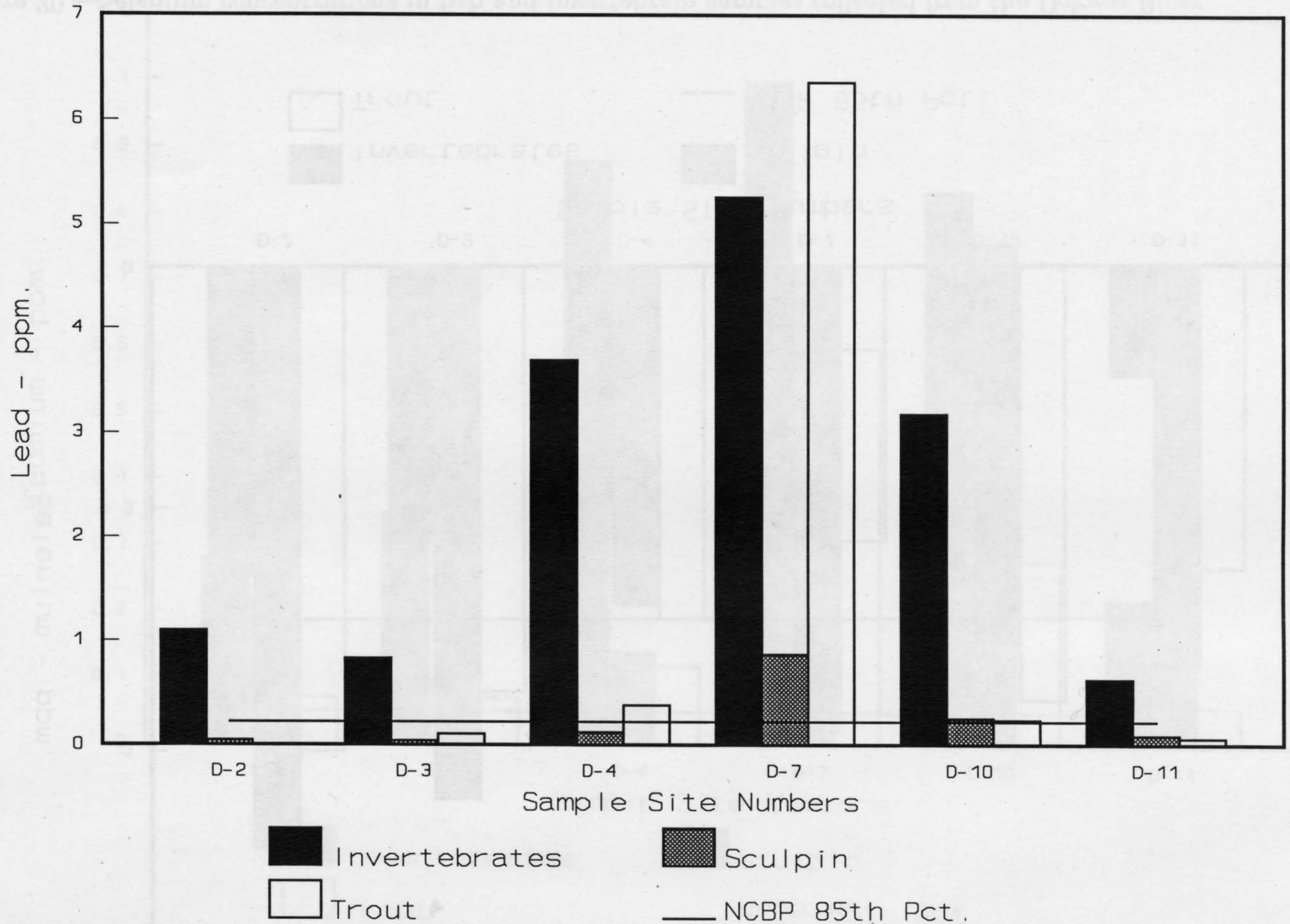

Figure 21.—Lead concentrations in fish and invertebrate samples collected from the Dolores River in September 1989.

Invertebrates show the highest zinc concentrations of any of the biological samples at all of the sample sites (figure 22). The fish samples show an increase above the NCBP baseline beginning at site D-7 below Rico. Sculpin Zn concentrations remain above the baseline at both of the sites downstream from D-7, while the Zn concentration in trout fall below the baseline at site D-11 (figure 22).

The five other contaminants analyzed in the upper Dolores River basin exceed their respective NCBP baseline for inorganic contaminants in fish in some or all of the samples. The comparisons include As (figure 18), Cd (figure 19), Se (figure 20), Pb (figure 21), and Zn (figure 22). Oddly enough, the only contaminant that was evaluated in biological media that did not exceed its equivalent NCBP baseline value was Hg. This result seems to indicate that there is possible contamination by a number of elements other than Hg in the basin above McPhee, while the Hg contamination is confined to McPhee Reservoir.

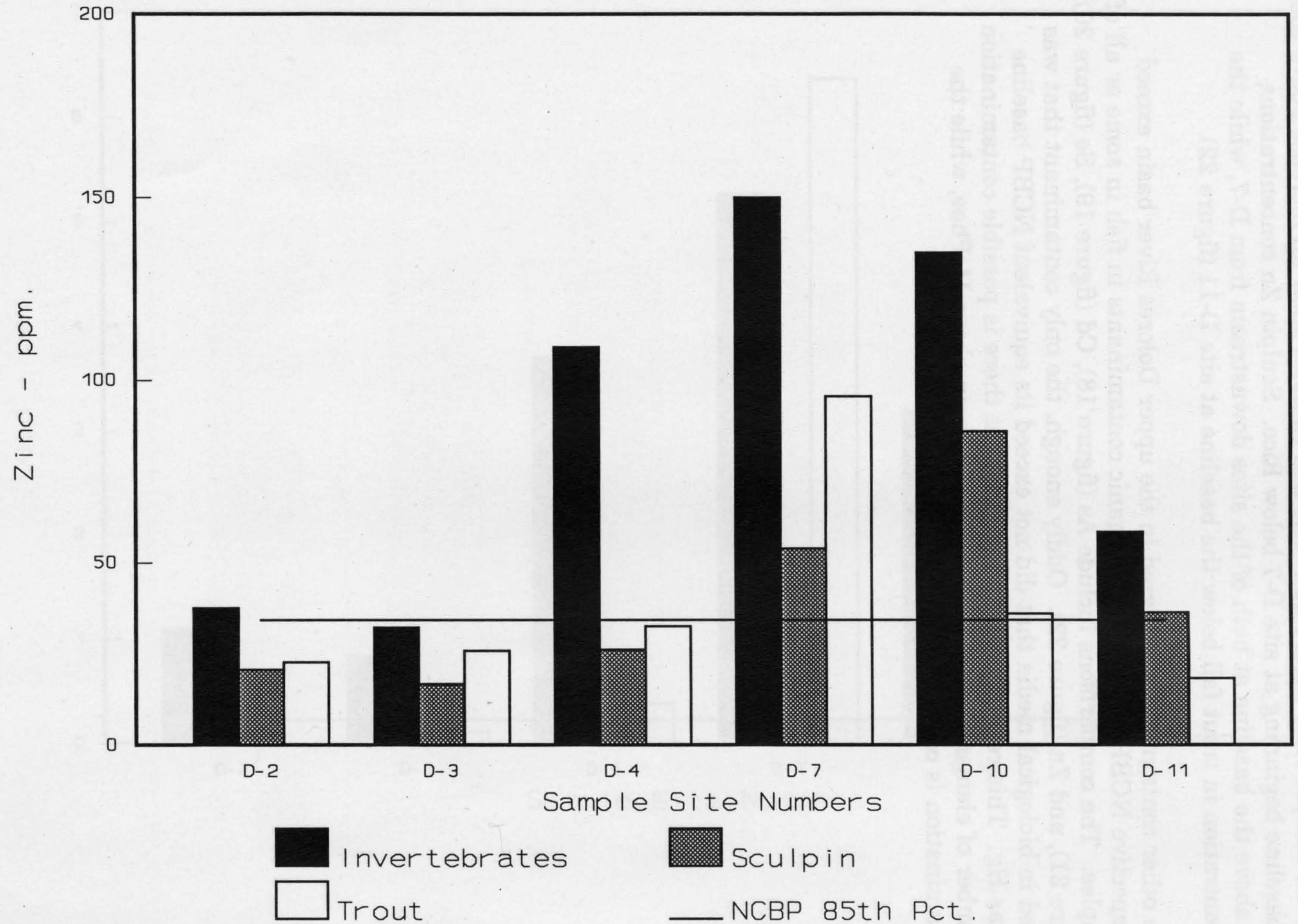

Figure 22.—Zinc concentrations in fish and invertebrate samples collected from the Dolores River in September 1989.

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ACRONYMS AND ABBREVIATIONS

EC	Electrical conductivity
Eh	Reduction-oridation potential
EPA	Environmental Protection Agency
eq/L	Equivalents per liter
FDA	Food and Drug Administration
ft^3/s	Cubic feet per second
lb	Pound
lb/day	Pound per day
mg/L	Milligram per liter
MINTEQ	EPA chemical equilibrium computer code
NCBP	National Contaminants Biomonitoring Program
oz	Ounce
%	Percent
pH	Hydrogen-ion concentration (negative logarithm of...)
ppm	Part per million
Reclamation	Bureau of Reclamation
TDS	Total dissolved solids
USGS	U.S. Geological Survey
µg/L	Microgram per liter
µS/cm	Micro-siemens per centimeter
UWRL	Utah Water Research Laboratory
WATEQ	USGS chemical equilibrium computer code

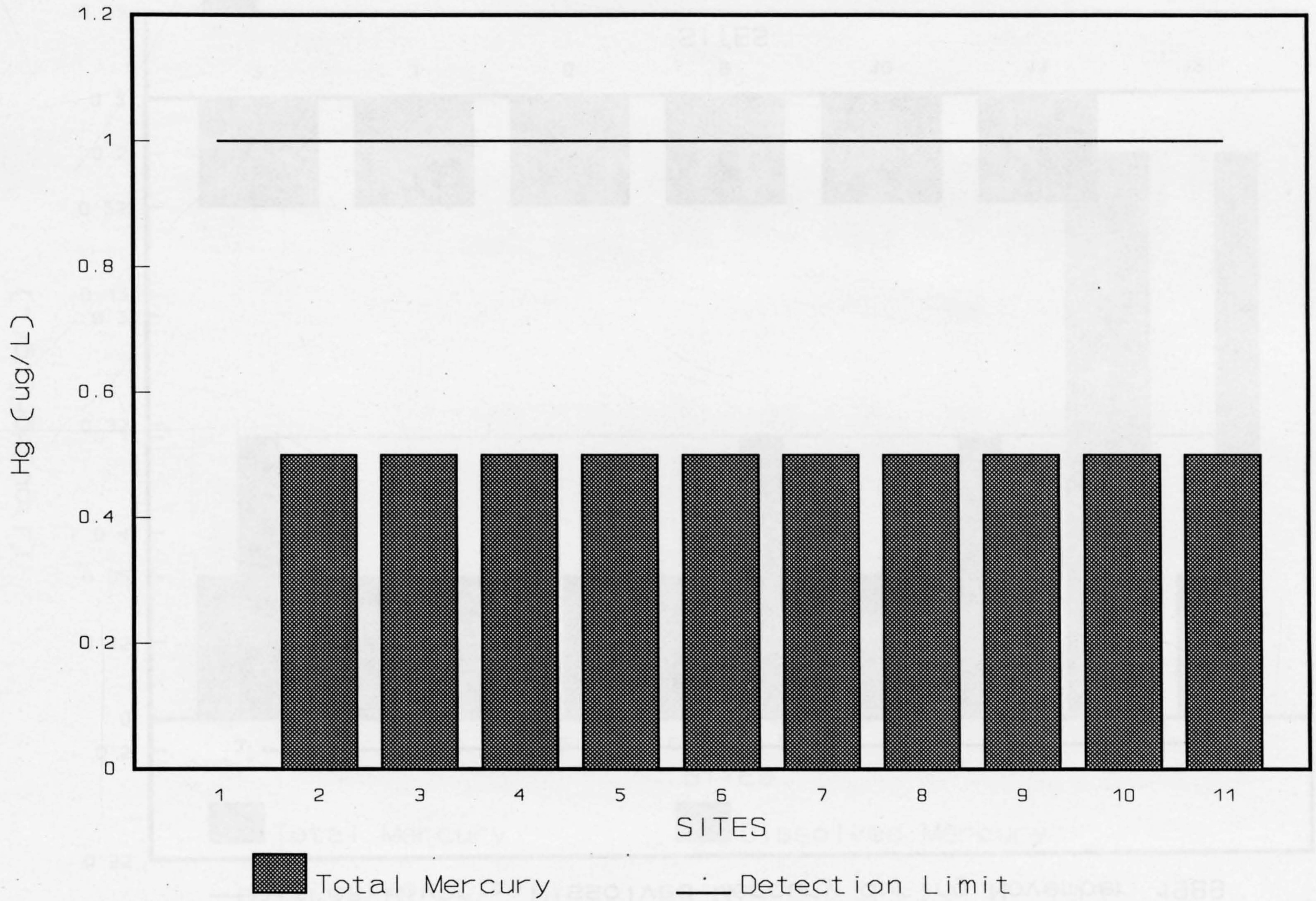
CHEMICAL AND MINERAL SYMBOLS

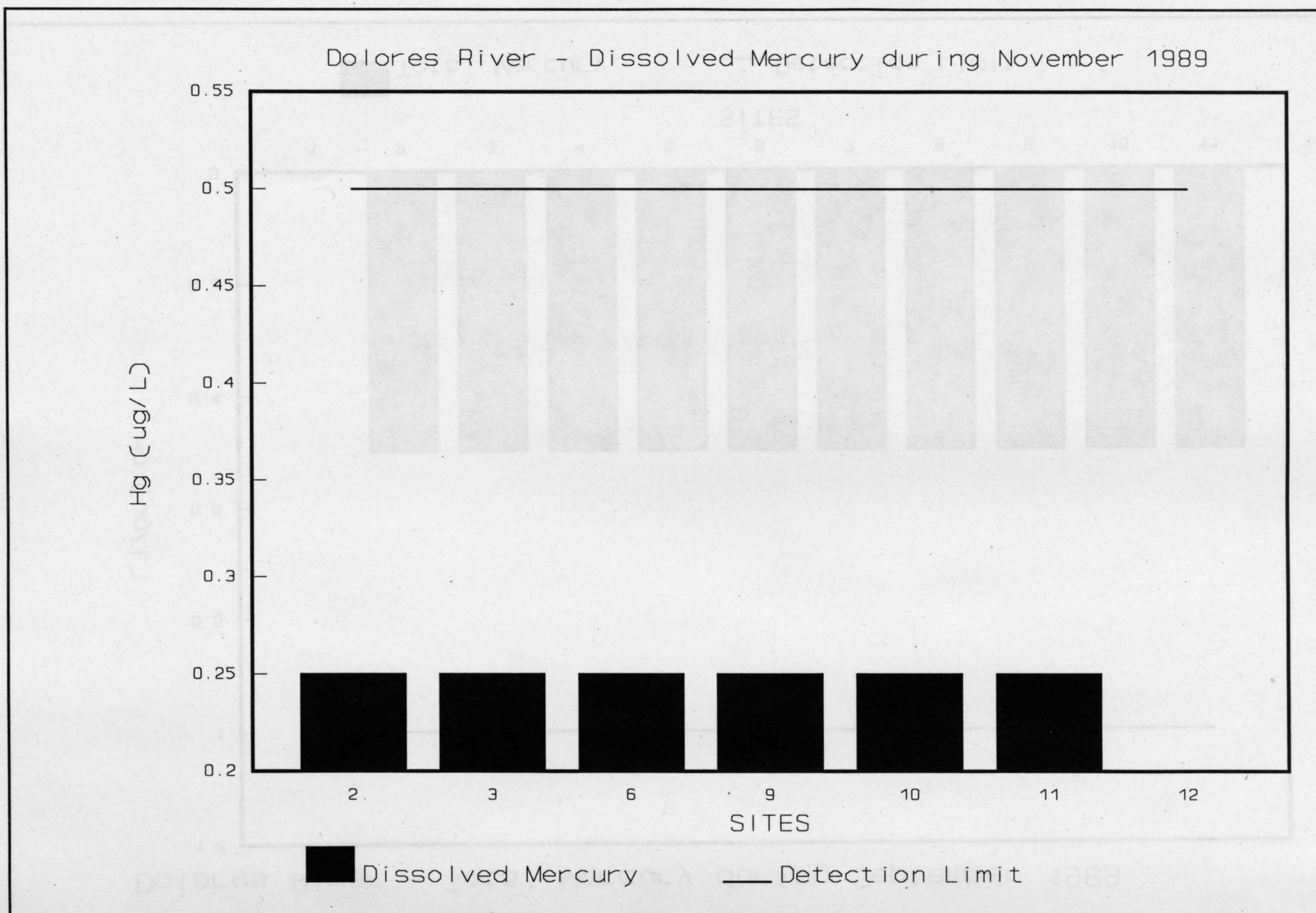
Ag	Silver	Hg(g)	Gaseous mercury
Al	Aluminum	Li	Lithium
As	Arsenic	Mg	Magnesium
B	Boron	Mn	Manganese
Ba	Barium 3	Ni	Nickel
Be	Beryllium	Pb	Lead
Ca	Calcium	Se	Selenium
Cd	Cadmium	Si	Silicon
Co	Cobalt	Sn	Tin
Cr	Chromium	Tl	Thallium
Cu	Copper	U	Uranium
Fe	Iron	V	Vanadium
Hg	Mercury	Zn	Zinc

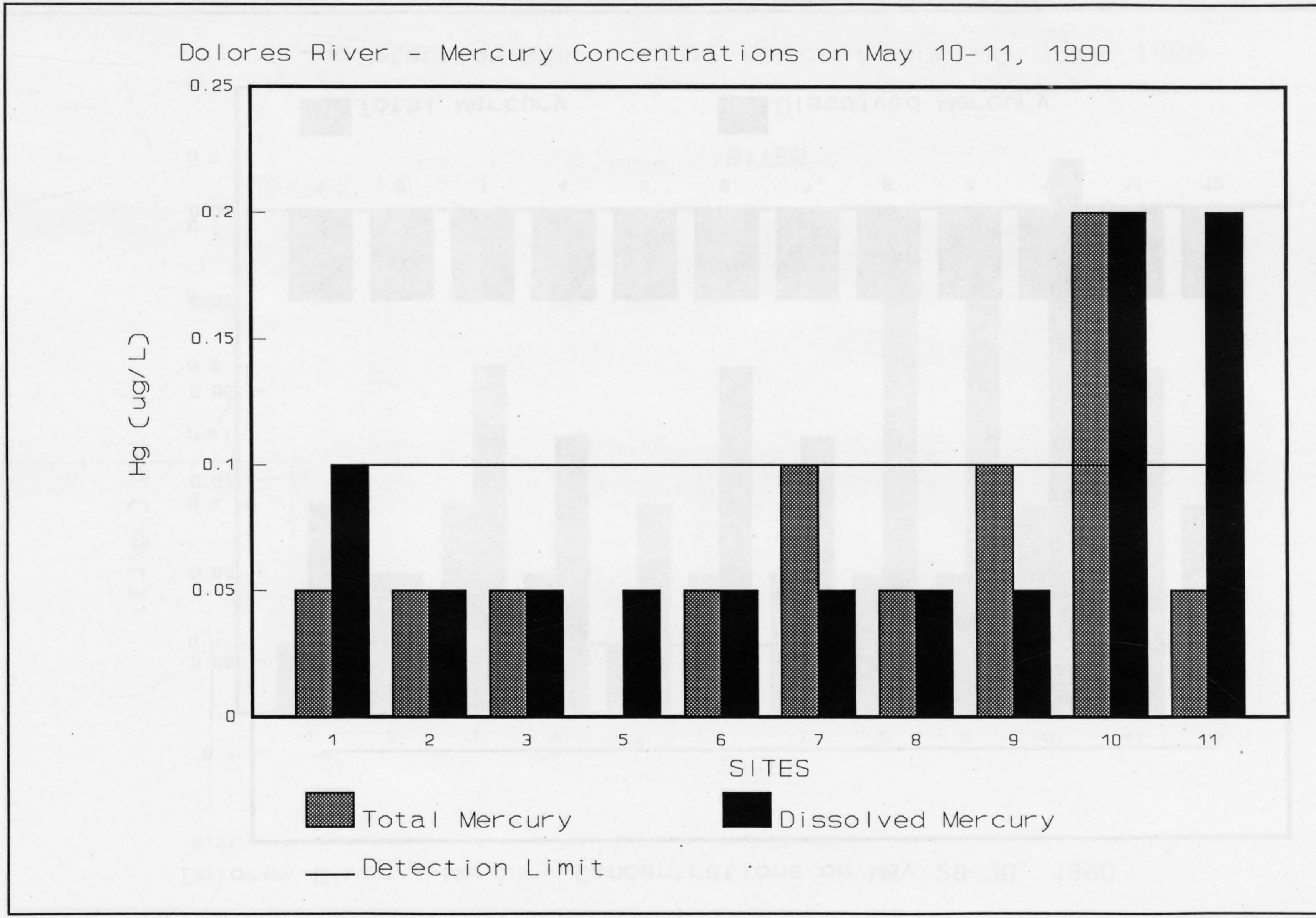
APPENDIX A

Plots of Mercury Data

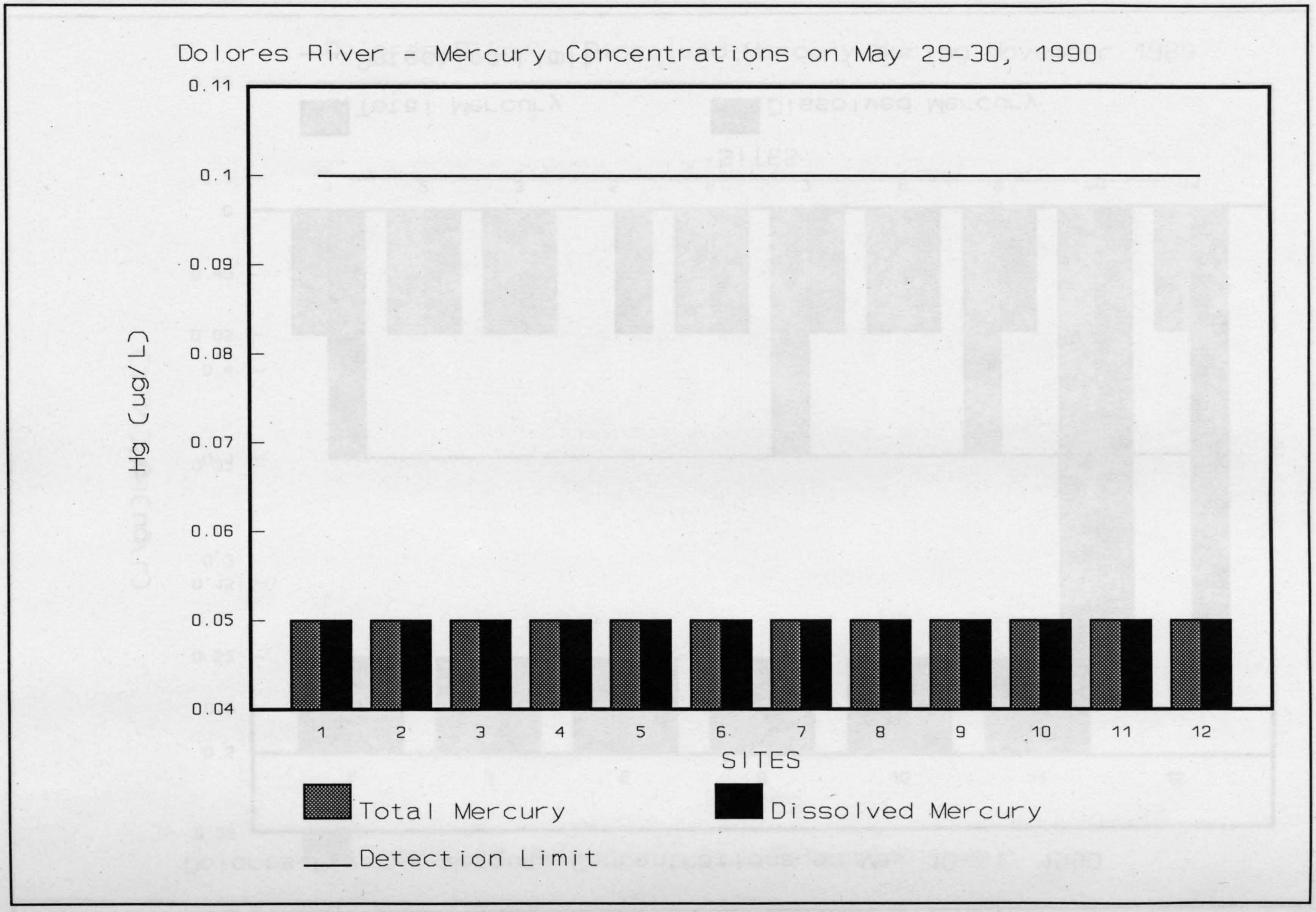
Dolores River - Total Mercury during September 1989

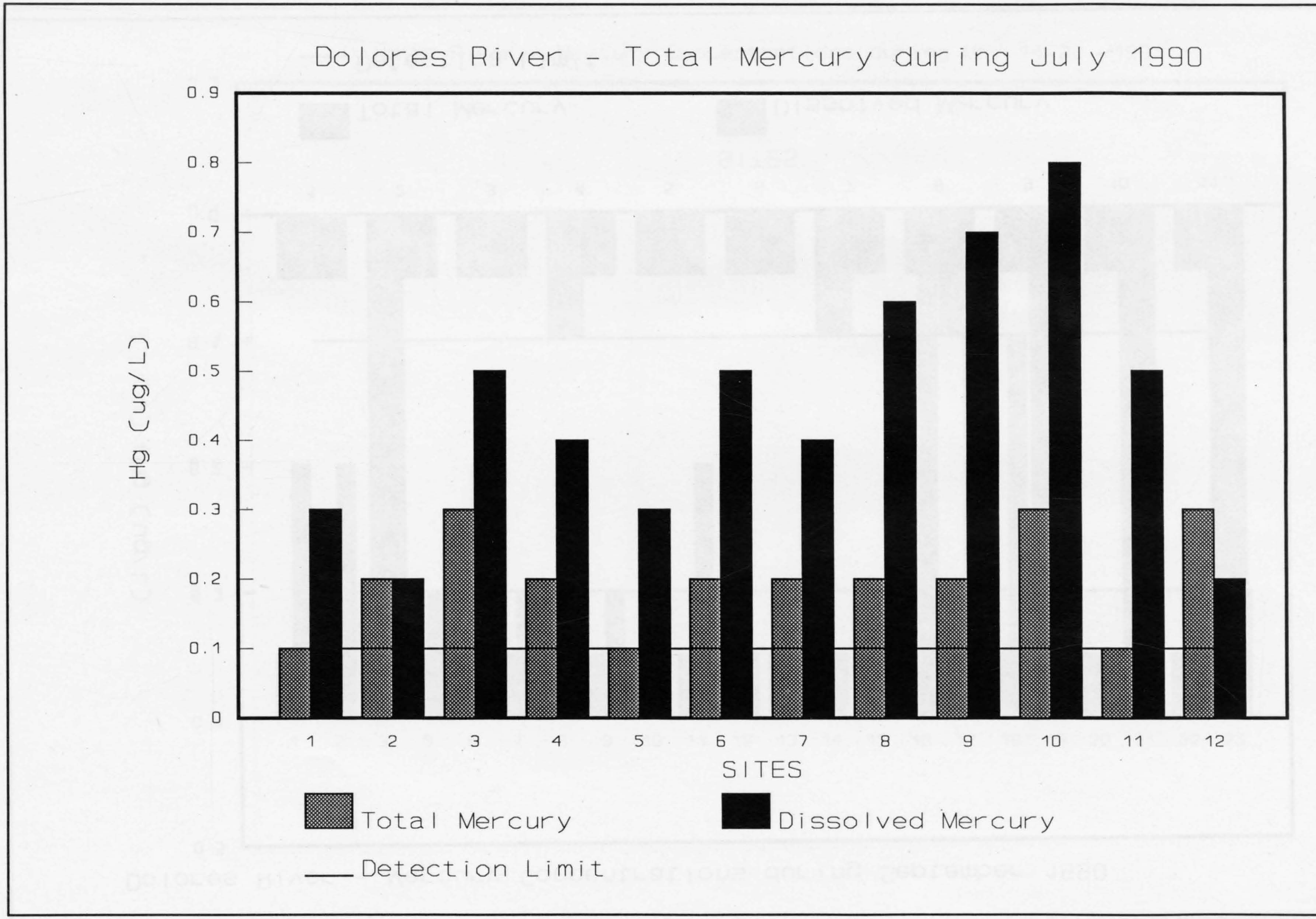


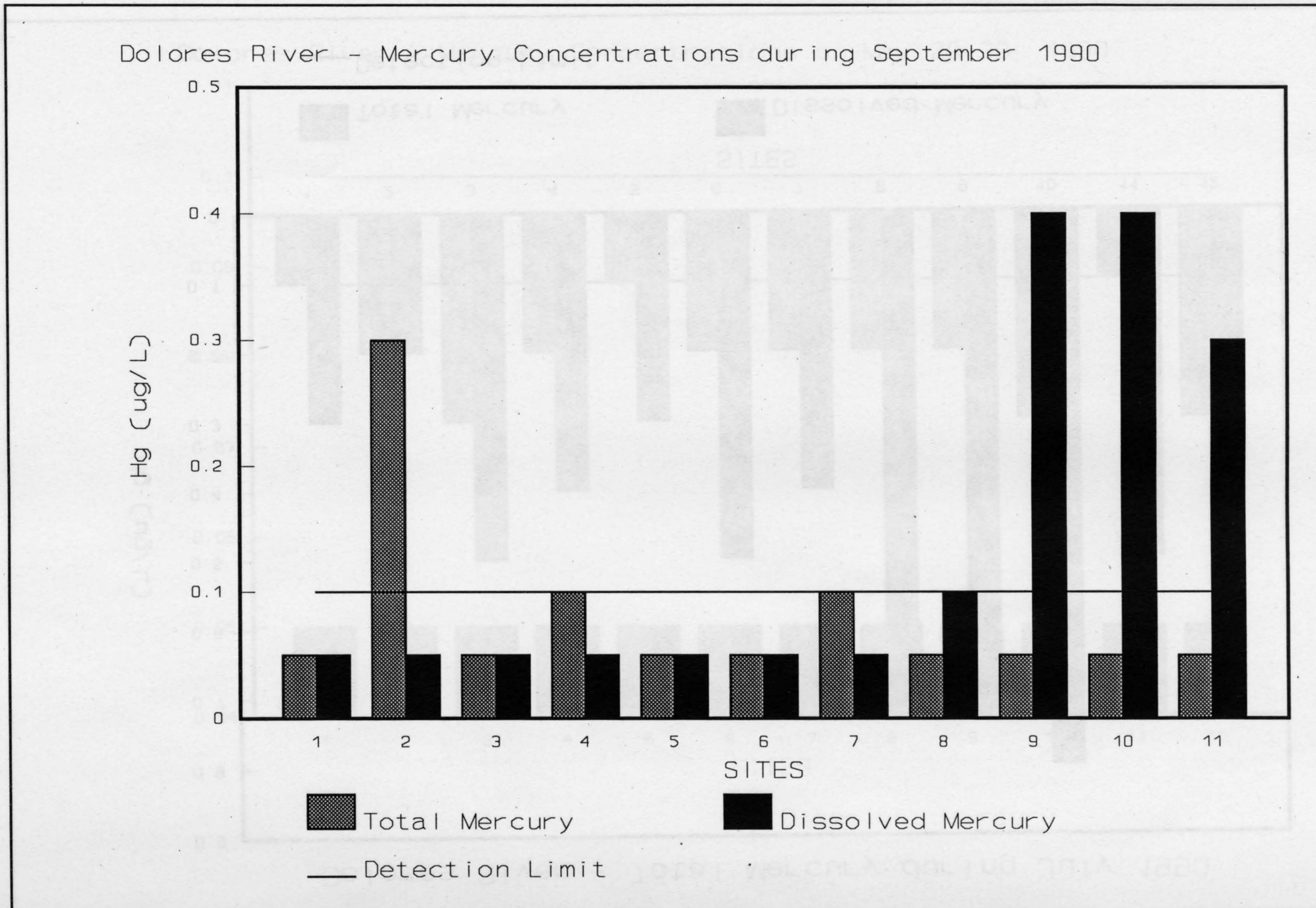

Dolores River - Dissolved Mercury during November 1989
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
Hg (ug/L)
2
3
6
9
10
11
12
SITES
Dissolved Mercury
Detection Limit



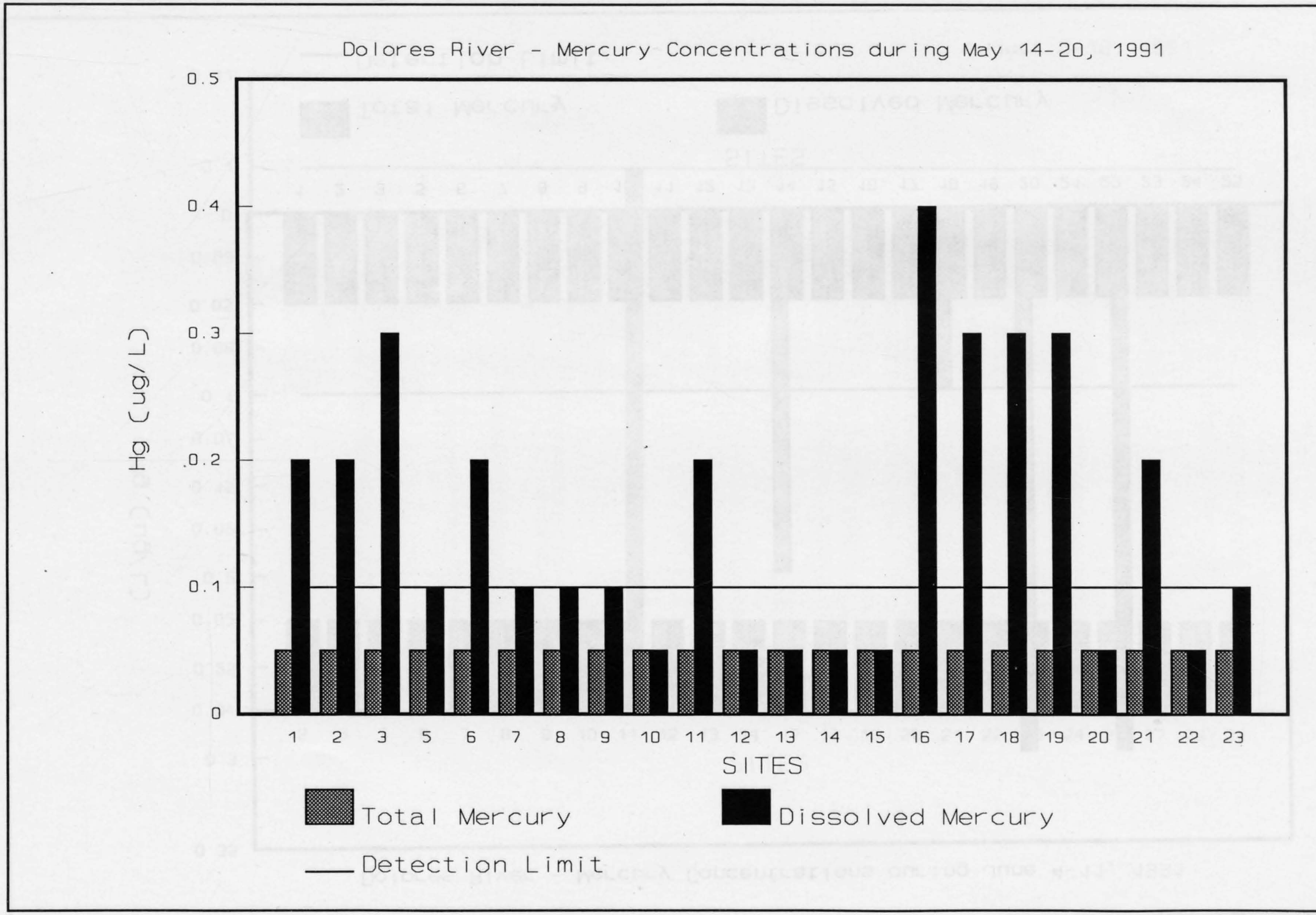
Dolores River - Mercury Concentrations on May 10-11, 1990
Hg (ug/L)
0.25
0.2
0.15
0.1
0.05
0
1
2
3
5
6
7
8
9
10
11
SITES
Total Mercury
Dissolved Mercury
Detection Limit

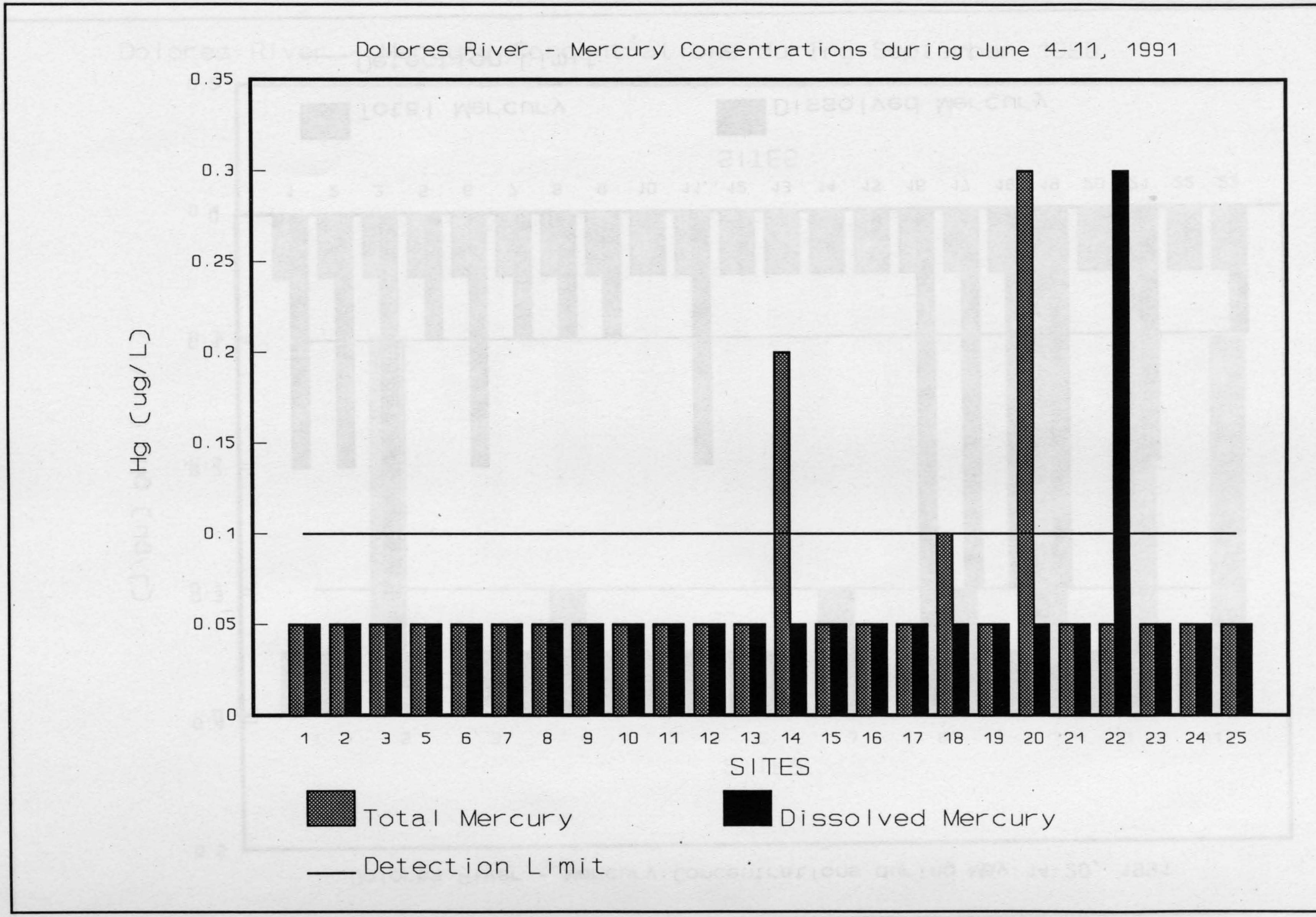

Dolores River - Mercury Concentrations on May 29-30, 1990
Hg (ug/L)
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
1
2
3
4
5
6
7
8
9
10
11
12
SITES
Total Mercury
Dissolved Mercury
Detection Limit


Dolores River - Total Mercury during July 1990
Hg (ug/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
SITES
Total Mercury
Dissolved Mercury
Detection Limit

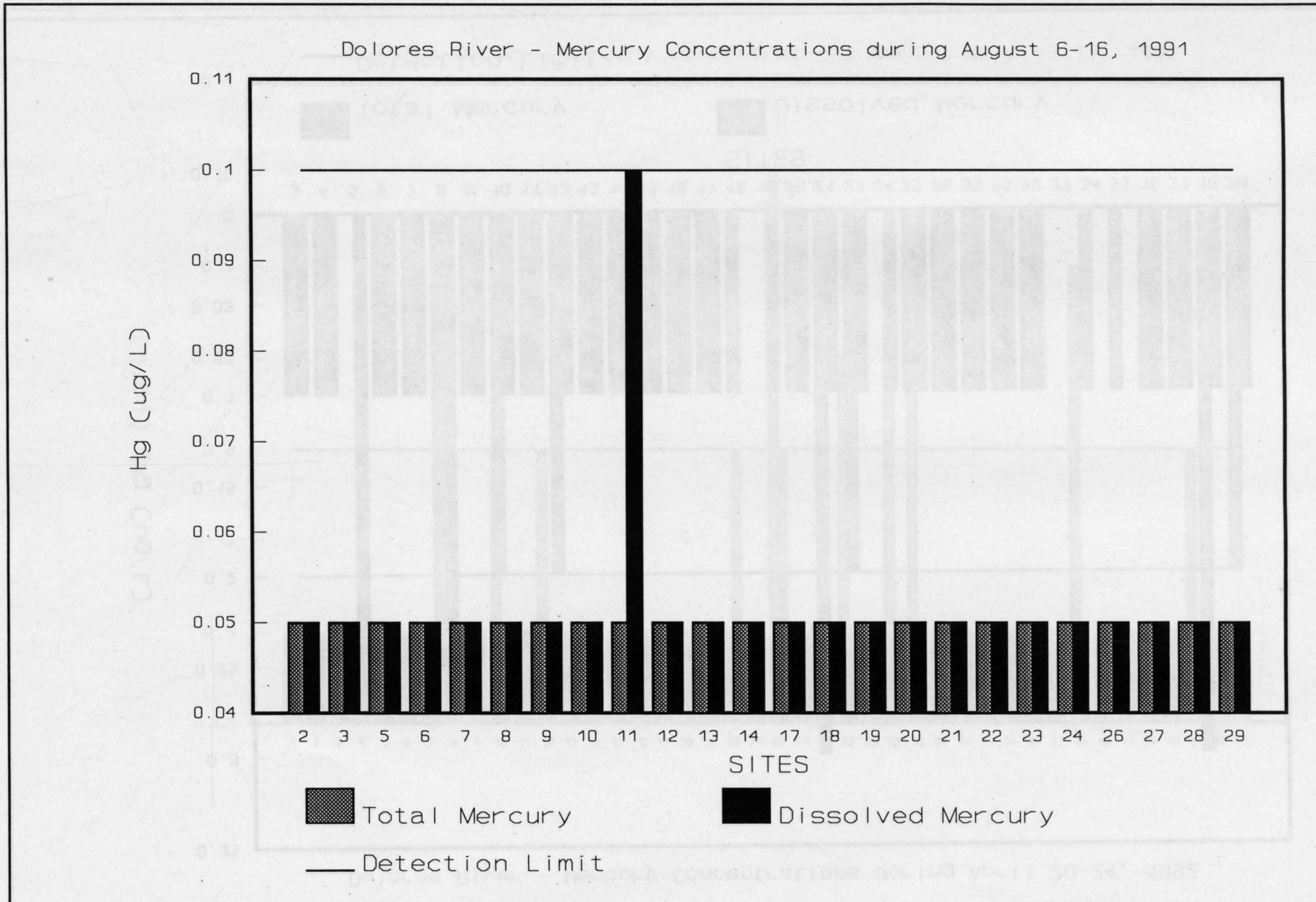


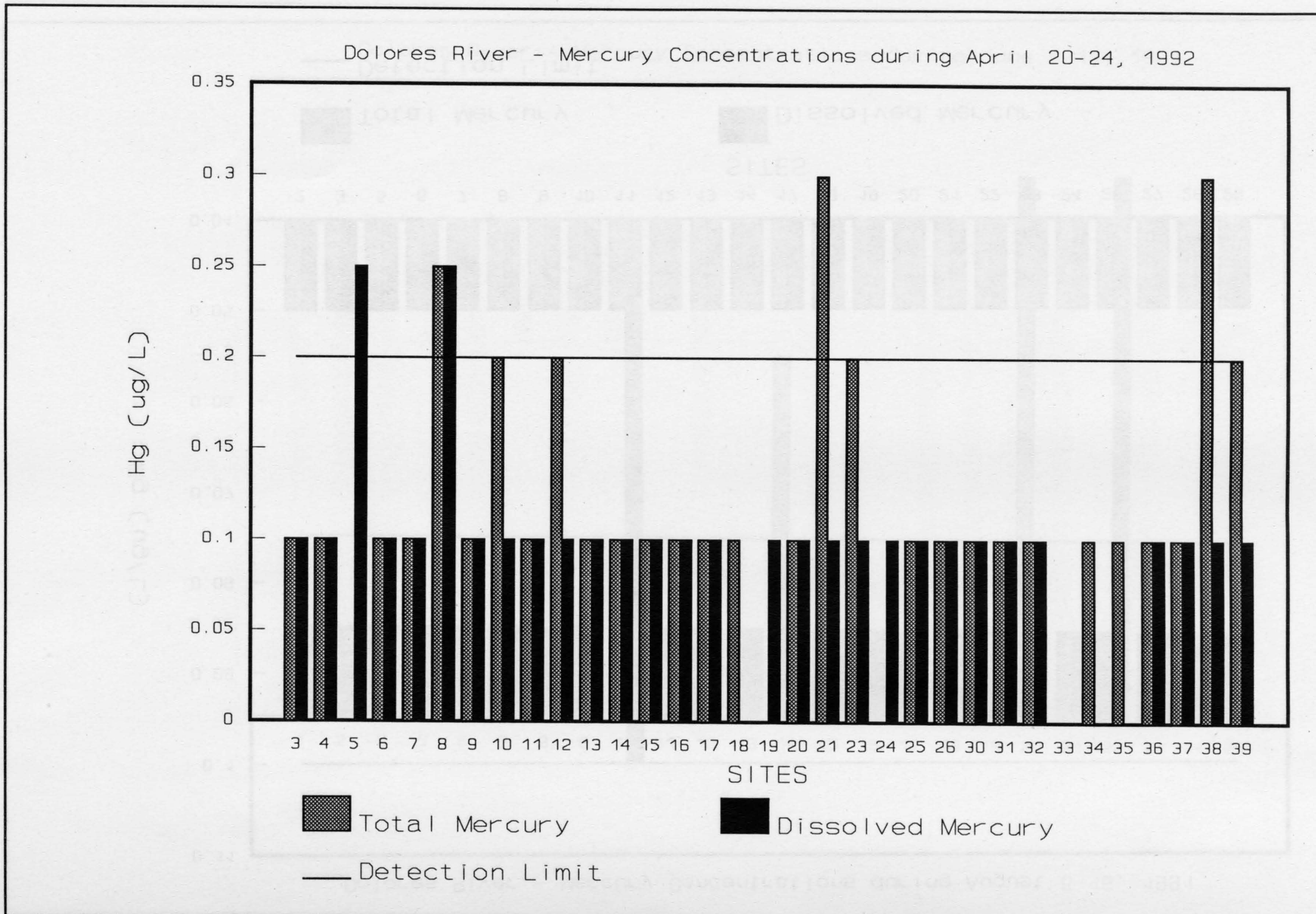
Dolores River - Mercury Concentrations during September 1990
Hg (ug/L)
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
SITES
Total Mercury
Dissolved Mercury
Detection Limit

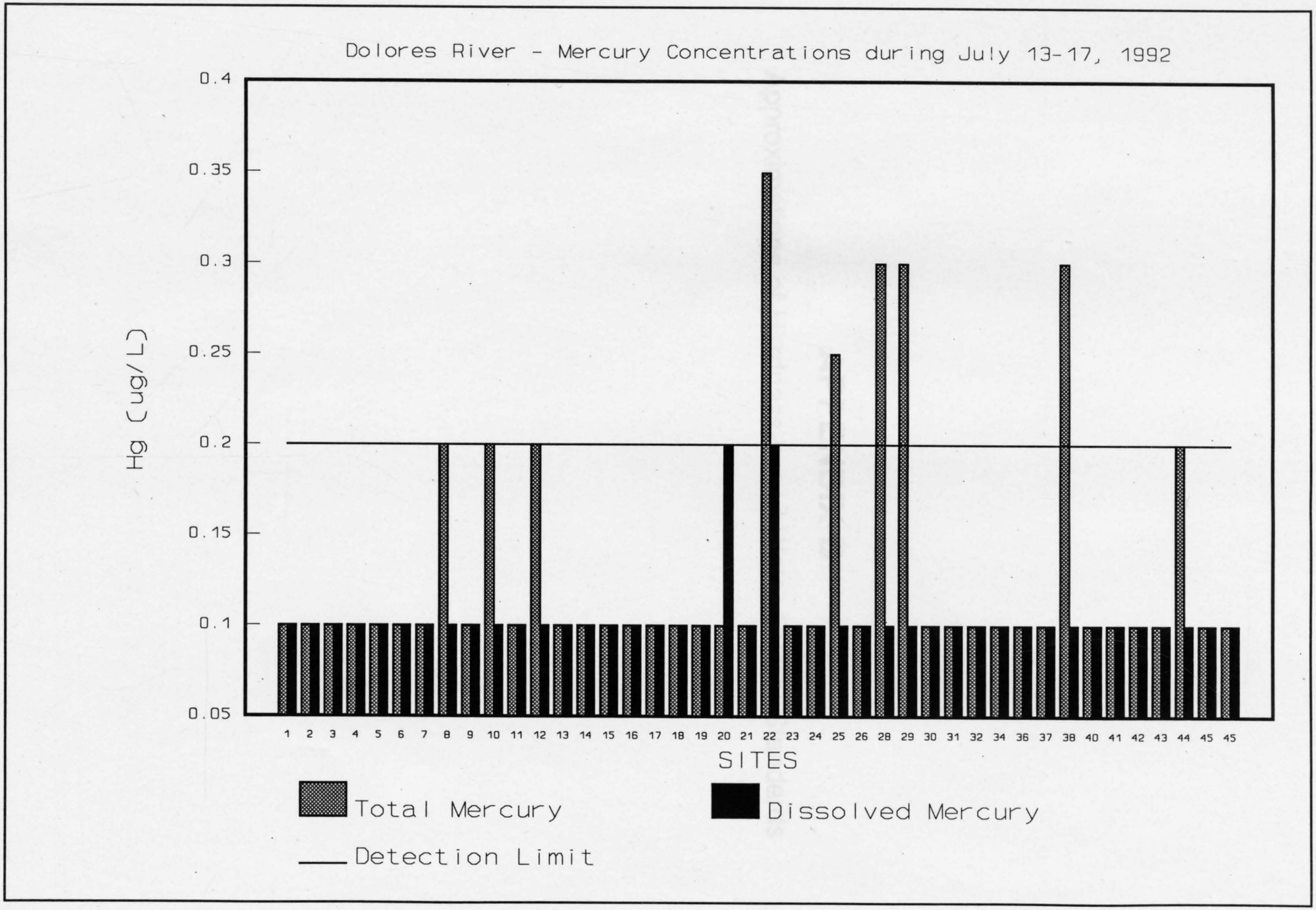

Dolores River - Mercury Concentrations during May 14-20, 1991
Hg (ug/L)
0.5
0.4
0.3
0.2
0.1
0
1 2 3 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
SITES
Total Mercury
Dissolved Mercury
Detection Limit



Dolores River - Mercury Concentrations during June 4-11, 1991
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Hg (ug/L)
1 2 3 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
SITES
Total Mercury
Dissolved Mercury
Detection Limit


Dolores River - Mercury Concentrations during August 6-16, 1991
Hg (ug/L)
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
2 3 5 6 7 8 9 10 11 12 13 14 17 18 19 20 21 22 23 24 26 27 28 29
SITES
Total Mercury
Dissolved Mercury
Detection Limit


Dolores River - Mercury Concentrations during April 20-24, 1992
Hg (ug/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 23 24 25 26 30 31 32 33 34 35 36 37 38 39
SITES
Total Mercury
Dissolved Mercury
Detection Limit


Dolores River - Mercury Concentrations during July 13-17, 1992
Hg (ug/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 28 29 30 31 32 34 36 37 38 40 41 42 43 44 45 45
SITES
Total Mercury
Dissolved Mercury
Detection Limit

APPENDIX B

Approximations of Hardness-based Water Quality Standards

DOLORES RIVER MERCURY STUDY - ACUTE WATER QUALITY STANDARD LEVELS (μg/L)[1]

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL01T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL01T	11-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL01T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL01T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL01T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL01T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL01T	04-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL01T	27-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL01T	15-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL02T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL02T	17-Nov-89	--	--	--	--	--	--	--	--	--	--
DRDOL02T	11-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL02T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL02T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL02T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL02T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL02T	04-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL02T	16-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL02T	15-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL03T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL03T	17-Nov-89	--	--	--	--	--	--	--	--	--	--
DRDOL03T	10-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL03T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL03T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL03T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL03T	16-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL03T	06-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL03T	16-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL03T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL03T	15-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL04T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL04T	29-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL04T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL04T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL04T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL04T	13-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL05T	19-Sep-89	ND	ND	--	10	ND	50	ND	--	ND	ND
DRDOL05T	11-May-90	3.6	16.7	--	10	1.8	50	1.6	--	86.5	5.5
DRDOL05T	29-May-90	ND	ND	--	10	ND	50	ND	--	ND	ND
DRDOL05T	11-Jul-90	2.0	10.0	--	10	0.7	50	1.0	--	35.8	3.6
DRDOL05T	07-Sep-90	2.2	11.1	--	10	0.9	50	1.1	--	43.2	3.9
DRDOL05T	20-May-91	2.3	11.3	--	10	0.9	50	1.1	--	44.1	4.0
DRDOL05T	11-Jun-91	2.1	10.3	--	10	0.8	50	1.0	--	38.0	3.7
DRDOL05T	09-Aug-91	2.3	11.2	--	10	0.9	50	1.1	--	43.5	4.0
DRDOL05T	24-Apr-92	3.9	17.8	--	10	2.0	50	1.7	--	96.0	5.7
DRDOL05T	13-Jul-92	2.1	10.7	--	10	0.8	50	1.1	--	40.0	3.8
DRDOL06T	17-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL06T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL06T	17-Nov-89	--	--	--	--	--	--	--	--	--	--
DRDOL06T	11-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL06T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL06T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL06T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL06T	16-May-91	--	--	--	--	--	--	--	--	--	--

[1] NOTE - Most of the Colorado water quality standards based on toxicity to aquatic life are to be computed from regression relationships based on long-term hardness data for the basin. No long-term hardness data are available for the Upper Dolores Basin. Estimates of trace element concentrations equivalent to those of standards are based on the instantaneous hardness at the time the sample was collected.

DOLORES RIVER MERCURY STUDY - ACUTE WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL06T	04-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL06T	12-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL06T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL06T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL07T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL07T	11-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL07T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL07T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL07T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL07T	16-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL07T	06-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL07T	08-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL07T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL07T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL08T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL08T	11-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL08T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL08T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL08T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL08T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL08T	04-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL08T	13-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL08T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL08T	15-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL09T	19-Sep-89	ND	ND	--	10	ND	50	ND	--	ND	ND
DRDOL09T	17-Nov-89	7.3	29.8	--	10	5.2	50	2.6	--	233.1	8.7
DRDOL09T	11-May-90	3.6	16.5	--	10	1.8	50	1.6	--	85.0	5.4
DRDOL09T	30-May-90	ND	ND	--	10	ND	50	ND	--	ND	ND
DRDOL09T	11-Jul-90	4.9	21.4	--	10	2.9	50	1.9	--	132.1	6.7
DRDOL09T	07-Sep-90	6.5	27.2	--	10	4.4	50	2.4	--	199.5	8.1
DRDOL09T	15-May-91	2.6	12.5	--	10	1.1	50	1.2	--	53.0	4.3
DRDOL09T	04-Jun-91	3.4	15.8	--	10	1.6	50	1.5	--	78.5	5.2
DRDOL09T	08-Aug-91	5.2	22.6	--	10	3.2	50	2.0	--	145.3	7.0
DRDOL09T	21-Apr-92	4.4	19.4	--	10	2.4	50	1.8	--	111.9	6.2
DRDOL09T	15-Jul-92	5.1	22.0	--	10	3.0	50	2.0	--	138.5	6.8
DRDOL10T	17-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL10T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL10T	17-Nov-89	--	--	--	--	--	--	--	--	--	--
DRDOL10T	10-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	29-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	29-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	29-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL10T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL10T	06-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL10T	08-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL10T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL10T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL11T	19-Sep-89	--	--	--	--	--	--	--	--	--	--
DRDOL11T	17-Nov-89	--	--	--	--	--	--	--	--	--	--
DRDOL11T	10-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL11T	30-May-90	--	--	--	--	--	--	--	--	--	--
DRDOL11T	11-Jul-90	--	--	--	--	--	--	--	--	--	--
DRDOL11T	07-Sep-90	--	--	--	--	--	--	--	--	--	--
DRDOL11T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL11T	04-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL11T	16-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL11T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL11T	14-Jul-92	--	--	--	--	--	--	--	--	--	--

DOLORES RIVER MERCURY STUDY - ACUTE WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL12T	14-Nov-89	9.8	38.2	--	10	8.2	50	3.2	--	356.3	10.6
DRDOL12T	20-Dec-89	13.1	48.7	--	10	12.8	50	3.9	--	540.6	12.9
DRDOL12T	29-May-90	ND	ND	--	10	ND	50	ND	--	ND	ND
DRDOL12T	29-May-90	2.7	13.0	--	10	1.1	50	1.3	--	56.0	4.5
DRDOL12T	13-Jun-90	2.9	13.9	--	10	1.3	50	1.3	--	62.8	4.7
DRDOL12T	11-Jul-90	4.8	20.9	--	10	2.7	50	1.9	--	126.7	6.5
DRDOL12T	29-Aug-90	5.9	25.0	--	10	3.8	50	2.2	--	172.4	7.6
DRDOL12T	14-May-91	2.7	12.9	--	10	1.1	50	1.3	--	55.3	4.4
DRDOL12T	04-Jun-91	3.7	16.9	--	10	1.9	50	1.6	--	87.9	5.5
DRDOL12T	05-Jun-91	3.6	16.6	--	10	1.8	50	1.6	--	85.1	5.4
DRDOL12T	06-Aug-91	4.9	21.5	--	10	2.9	50	2.0	--	133.7	6.7
DRDOL12T	20-Apr-92	4.2	18.8	--	10	2.2	50	1.7	--	105.5	6.0
DRDOL12T	15-Jul-92	4.9	21.3	--	10	2.8	50	1.9	--	131.2	6.6
DRDOL13T	15-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL13T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL13T	12-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL13T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL13T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL14T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL14T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL14T	08-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL14T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL14T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL15T	15-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL15T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL15T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL15T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL16T	15-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL16T	11-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL16T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL16T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL17T	15-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL17T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL17T	13-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL17T	21-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL17T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL18T	14-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL18T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL18T	13-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL18T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL18T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL19T	16-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL19T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL19T	13-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL19T	22-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL19T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL20T	16-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL20T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL20T	13-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL20T	21-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL20T	15-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL21T	20-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL21T	11-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL21T	09-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL21T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL21T	13-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL22T	20-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL22T	11-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL22T	06-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL22T	13-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL23T	20-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL23T	11-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL23T	09-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL23T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL23T	13-Jul-92	--	--	--	--	--	--	--	--	--	--

DOLORES RIVER MERCURY STUDY - ACUTE WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL24T	24-May-91	3.3	15.3	--	10	1.6	50	0.7	--	74.4	5.1
DRDOL24T	04-Jun-91	4.4	19.4	--	10	2.4	50	0.9	--	112.0	6.2
DRDOL24T	08-Aug-91	4.4	19.4	--	10	2.4	50	0.9	--	111.6	6.2
DRDOL24T	21-Apr-92	4.6	20.1	--	10	2.5	50	0.9	--	118.6	6.3
DRDOL24T	14-Jul-92	4.7	20.6	--	10	2.7	50	0.9	--	123.8	6.5
DRDOL25T	22-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL25T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL25T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL25T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL26T	09-Aug-91	3.7	17.1	--	10	1.9	50	0.8	--	89.7	5.6
DRDOL26T	24-Apr-92	5.6	23.7	--	10	3.4	50	1.1	--	157.7	7.3
DRDOL26T	13-Jul-92	7.7	31.0	--	10	5.6	50	1.3	--	250.2	9.0
DRDOL27T	09-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL28T	12-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL28T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL29T	16-Aug-91	--	--	--	--	--	--	--	--	--	--
DRDOL29T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL30T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL30T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL31T	23-Apr-92	3.0	14.0	--	10	1.3	50	1.4		64.2	4.8
DRDOL31T	15-Jul-92	3.5	16.2	--	10	1.7	50	1.5		81.7	5.3
DRDOL32T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL32T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL33T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL34T	23-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL34T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL35T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL36T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL36T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL37T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL37T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL38T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL38T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL39T	24-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL40T	13-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL41T	13-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL42T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL43T	14-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL44T	16-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL45T	17-Jul-92	--	--	--	--	--	--	--	--	--	--

DOLORES RIVER MERCURY STUDY - CHRONIC WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL01T	19-Sep-89	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL01T	11-May-90	0.4	7.6	0.05	10	0.1	50	68	50	4	50
DRDOL01T	30-May-90	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL01T	11-Jul-90	0.4	7.4	0.05	10	0.1	50	67	50	4	50
DRDOL01T	07-Sep-90	0.4	9.6	0.05	10	0.1	50	86	50	4	50
DRDOL01T	14-May-91	0.4	7.0	0.05	10	0.1	50	63	50	4	50
DRDOL01T	04-Jun-91	0.4	6.8	0.05	10	0.1	50	61	50	4	50
DRDOL01T	27-Aug-91	0.4	10.1	0.05	10	0.1	50	91	50	4	50
DRDOL01T	15-Jul-92	0.4	7.9	0.05	10	0.1	50	71	50	4	50
DRDOL02T	19-Sep-89	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL02T	17-Nov-89	0.4	14.1	0.05	10	0.1	50	126	50	4	50
DRDOL02T	11-May-90	0.4	8.1	0.05	10	0.1	50	73	50	4	50
DRDOL02T	30-May-90	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL02T	11-Jul-90	0.4	9.2	0.05	10	0.1	50	83	50	4	50
DRDOL02T	07-Sep-90	0.4	11.7	0.05	10	0.1	50	104	50	4	50
DRDOL02T	14-May-91	0.4	7.0	0.05	10	0.1	50	63	50	4	50
DRDOL02T	04-Jun-91	0.4	7.4	0.05	10	0.1	50	67	50	4	50
DRDOL02T	16-Aug-91	0.4	10.9	0.05	10	0.1	50	98	50	4	50
DRDOL02T	15-Jul-92	0.4	9.5	0.05	10	0.1	50	85	50	4	50
DRDOL03T	19-Sep-89	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL03T	17-Nov-89	0.4	13.4	0.05	10	0.1	50	120	50	4	50
DRDOL03T	10-May-90	0.4	8.1	0.05	10	0.1	50	73	50	4	50
DRDOL03T	30-May-90	0.4	ND	0.05	10	0.1	50	ND	50	4	50
DRDOL03T	11-Jul-90	0.4	9.4	0.05	10	0.1	50	85	50	4	50
DRDOL03T	07-Sep-90	0.4	12.4	0.05	10	0.1	50	111	50	4	50
DRDOL03T	16-May-91	0.4	8.0	0.05	10	0.1	50	72	50	4	50
DRDOL03T	06-Jun-91	0.4	7.0	0.05	10	0.1	50	63	50	4	50
DRDOL03T	16-Aug-91	0.4	12.1	0.05	10	0.1	50	109	50	4	50
DRDOL03T	23-Apr-92	0.4	10.8	0.05	10	0.1	50	97	50	4	50
DRDOL03T	15-Jul-92	0.4	10.4	0.05	10	0.1	50	93	50	4	50
DRDOL04T	19-Sep-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL04T	29-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL04T	11-Jul-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL04T	07-Sep-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL04T	24-Apr-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL04T	13-Jul-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL05T	19-Sep-89	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	11-May-90	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	29-May-90	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	11-Jul-90	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	07-Sep-90	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	20-May-91	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	11-Jun-91	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	09-Aug-91	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	24-Apr-92	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL05T	13-Jul-92	0.4	5	0.05	--	0.1	50	50	50	4	50
DRDOL06T	17-Sep-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	19-Sep-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	17-Nov-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	11-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	30-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	11-Jul-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	07-Sep-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	16-May-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	04-Jun-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	12-Aug-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	23-Apr-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL06T	14-Jul-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10

DOLORES RIVER MERCURY STUDY - CHRONIC WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL07T	19-Sep-89	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	11-May-90	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	30-May-90	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	11-Jul-90	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	07-Sep-90	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	16-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	06-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	08-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL07T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL08T	19-Sep-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	11-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	30-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	11-Jul-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	07-Sep-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	14-May-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	04-Jun-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	13-Aug-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	22-Apr-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL08T	15-Jul-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL09T	19-Sep-89	ND	ND	0.01	--	ND	--	50	50	4	50
DRDOL09T	17-Nov-89	1.7	18.9	0.01	--	169	--	50	50	4	50
DRDOL09T	11-May-90	1.1	11.1	0.01	--	100	--	50	50	4	50
DRDOL09T	30-May-90	ND	ND	0.01	--	ND	--	50	50	4	50
DRDOL09T	11-Jul-90	1.3	14.0	0.01	--	125	--	50	50	4	50
DRDOL09T	07-Sep-90	1.6	17.4	0.01	--	156	--	50	50	4	50
DRDOL09T	15-May-91	0.9	8.6	0.01	--	78	--	50	50	4	50
DRDOL09T	04-Jun-91	1.0	10.6	0.01	--	95	--	50	50	4	50
DRDOL09T	08-Aug-91	1.4	14.7	0.01	--	132	--	50	50	4	50
DRDOL09T	21-Apr-92	1.2	12.8	0.01	--	115	--	50	50	4	50
DRDOL09T	15-Jul-92	1.4	14.4	0.01	--	129	--	50	50	4	50
DRDOL10T	17-Sep-89	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	19-Sep-89	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	17-Nov-89	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	10-May-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	29-May-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	29-May-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	29-May-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	11-Jul-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	07-Sep-90	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	14-May-91	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	06-Jun-91	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	08-Aug-91	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	23-Apr-92	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL10T	14-Jul-92	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL11T	19-Sep-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	17-Nov-89	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	10-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	30-May-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	11-Jul-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	07-Sep-90	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	14-May-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	04-Jun-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	16-Aug-91	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	23-Apr-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10
DRDOL11T	14-Jul-92	0.4	14.0	0.05	20	0.1	50	240	1000	4	10

DOLORES RIVER MERCURY STUDY - CHRONIC WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL12T	14-Nov-89	2.1	23.7	0.01	10	211	50	50	50	4	50
DRDOL12T	20-Dec-89	2.6	29.5	0.01	10	263	50	50	50	4	50
DRDOL12T	29-May-90	ND	ND	0.01	10	ND	50	50	50	4	50
DRDOL12T	29-May-90	0.9	8.9	0.01	10	80	50	50	50	4	50
DRDOL12T	13-Jun-90	0.9	9.5	0.01	10	85	50	50	50	4	50
DRDOL12T	11-Jul-90	1.3	13.7	0.01	10	123	50	50	50	4	50
DRDOL12T	29-Aug-90	1.5	16.1	0.01	10	144	50	50	50	4	50
DRDOL12T	14-May-91	0.9	8.8	0.01	10	79	50	50	50	4	50
DRDOL12T	04-Jun-91	1.1	11.3	0.01	10	101	50	50	50	4	50
DRDOL12T	05-Jun-91	1.1	11.1	0.01	10	100	50	50	50	4	50
DRDOL12T	06-Aug-91	1.3	14.1	0.01	10	126	50	50	50	4	50
DRDOL12T	20-Apr-92	1.2	12.4	0.01	10	111	50	50	50	4	50
DRDOL12T	15-Jul-92	1.3	14.0	0.01	10	125	50	50	50	4	50
DRDOL13T	15-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL13T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL13T	12-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL13T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL13T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL14T	14-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL14T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL14T	08-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL14T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL14T	17-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL15T	15-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL15T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL15T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL15T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL16T	15-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL16T	11-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL16T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL16T	14-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL17T	15-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL17T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL17T	13-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL17T	21-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL17T	17-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL18T	14-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL18T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL18T	13-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL18T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL18T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL19T	16-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL19T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL19T	13-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL19T	22-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL19T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL20T	16-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL20T	10-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL20T	13-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL20T	21-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL20T	15-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL21T	20-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL21T	11-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL21T	09-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL21T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL21T	13-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL22T	20-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL22T	11-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL22T	06-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL22T	13-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL23T	20-May-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL23T	11-Jun-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL23T	09-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL23T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL23T	13-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50

DOLORES RIVER MERCURY STUDY - CHRONIC WATER QUALITY STANDARD LEVELS (µg/L)

STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL24T	24-May-91	0.4	5	0.05	--	0.1	--	50	50	4	50
DRDOL24T	04-Jun-91	0.4	5	0.05	--	0.1	--	50	50	4	50
DRDOL24T	08-Aug-91	0.4	5	0.05	--	0.1	--	50	50	4	50
DRDOL24T	21-Apr-92	0.4	5	0.05	--	0.1	--	50	50	4	50
DRDOL24T	14-Jul-92	0.4	5	0.05	--	0.1	--	50	50	4	50
DRDOL25T	22-May-91	--	--	--	--	--	--	--	--	--	--
DRDOL25T	10-Jun-91	--	--	--	--	--	--	--	--	--	--
DRDOL25T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL25T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL26T	09-Aug-91	0.4	5	0.05	10	0.1	50	50	50	4	50
DRDOL26T	24-Apr-92	0.4	5	0.05	10	0.1	50	50	50	4	50
DRDOL26T	13-Jul-92	0.4	5	0.05	10	0.1	50	50	50	4	50
DRDOL27T	09-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL28T	12-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL28T	14-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL29T	16-Aug-91	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL29T	14-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL30T	20-Apr-92	--	--	--	--	--	--	--	--	--	--
DRDOL30T	17-Jul-92	--	--	--	--	--	--	--	--	--	--
DRDOL31T	23-Apr-92	0.9	9.6	0.01	--	0.05	--	45	50	2.74	79
DRDOL31T	15-Jul-92	1.0	10.9	0.01	--	0.06	--	45	50	3.38	89
DRDOL32T	23-Apr-92	0.4	22	0.05	10	0.1	50	100	50	4	50
DRDOL32T	16-Jul-92	0.4	22	0.05	10	0.1	50	100	50	4	50
DRDOL33T	23-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL34T	23-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL34T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL35T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL36T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL36T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL37T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL37T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL38T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL38T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL39T	24-Apr-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL40T	13-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL41T	13-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL42T	14-Jul-92	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL43T	14-Jul-92	6	20	0.05	20	0.1	50	1400	1000	16	50
DRDOL44T	16-Jul-92	0.4	5.0	0.05	10	0.1	50	50	50	4	50
DRDOL45T	17-Jul-92	--	--	--	--	--	--	--	--	--	--

APPENDIX C

Comparison of Water Quality Data to Aquatic Life Criteria

DOLORES RIVER MERCURY STUDY - COMPARISON TO AQUATIC LIFE CRITERIA

		EXCEEDENCES OF CHRONIC WATER QUALITY STANDARDS									
STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL01T	19-Sep-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL01T	11-May-90	NC		NC	NC	NC				NC	
DRDOL01T	30-May-90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL01T	11-Jul-90	*		*	NC	NC				NC	
DRDOL01T	07-Sep-90	NC		NC	NC	NC				NC	
DRDOL01T	14-May-91			NC	NC	NC				NC	
DRDOL01T	04-Jun-91			NC	NC	NC				NC	
DRDOL01T	27-Aug-91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL01T	15-Jul-92			NC							
DRDOL02T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL02T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL02T	11-May-90	NC		NC	NC	*				NC	
DRDOL02T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL02T	11-Jul-90	NC		*	NC	NC				NC	
DRDOL02T	07-Sep-90	NC		*	NC	NC				NC	
DRDOL02T	14-May-91	*		NC	NC	NC				NC	
DRDOL02T	04-Jun-91			NC	NC	NC				NC	
DRDOL02T	16-Aug-91			NC	NC	NC				NC	
DRDOL02T	15-Jul-92			NC							
DRDOL03T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL03T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL03T	10-May-90	NC		NC	NC	*				NC	
DRDOL03T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL03T	11-Jul-90	*		*	NC	NC				NC	
DRDOL03T	07-Sep-90	NC		NC	NC	NC				NC	
DRDOL03T	16-May-91			NC	NC	NC				NC	
DRDOL03T	06-Jun-91			NC	NC	NC				NC	
DRDOL03T	16-Aug-91			NC	NC	NC				NC	
DRDOL03T	23-Apr-92	ND		NC	ND						
DRDOL03T	15-Jul-92			NC							
DRDOL04T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL04T	29-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL04T	11-Jul-90	NC		*	NC	NC				NC	
DRDOL04T	07-Sep-90	NC		*	NC	NC				NC	
DRDOL04T	24-Apr-92	ND	*	NC	ND		ND			ND	
DRDOL04T	13-Jul-92			NC							
DRDOL05T	19-Sep-89	NC	ND	NC	ND	NC		ND	ND	NC	ND
DRDOL05T	11-May-90	ND	ND	ND	ND	ND	ND	ND		ND	ND
DRDOL05T	29-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL05T	11-Jul-90	*	*	*	ND	NC				NC	
DRDOL05T	07-Sep-90	NC		NC	ND	NC				*	
DRDOL05T	20-May-91			NC	ND	NC				NC	
DRDOL05T	11-Jun-91			NC	ND	NC				NC	
DRDOL05T	09-Aug-91			NC	ND	NC				NC	
DRDOL05T	24-Apr-92	ND	ND	ND	ND	ND	ND	ND		ND	ND
DRDOL05T	13-Jul-92			NC	ND						

DOLORES RIVER MERCURY STUDY - COMPARISON TO AQUATIC LIFE CRITERIA

		EXCEEDENCES OF CHRONIC WATER QUALITY STANDARDS									
STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL06T	17-Sep-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL06T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL06T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL06T	11-May-90	NC		NC	NC	*				NC	
DRDOL06T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL06T	11-Jul-90	NC		*	NC	NC				NC	
DRDOL06T	07-Sep-90	NC		NC	NC	NC				NC	
DRDOL06T	16-May-91			NC	NC	NC				NC	
DRDOL06T	04-Jun-91			NC	NC	NC				NC	
DRDOL06T	12-Aug-91			NC	NC	NC				NC	
DRDOL06T	23-Apr-92			NC		ND					
DRDOL06T	14-Jul-92			NC							
DRDOL07T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL07T	11-May-90	NC		*	NC	NC				NC	
DRDOL07T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL07T	11-Jul-90	NC		*	NC	NC				NC	
DRDOL07T	07-Sep-90	NC		*	NC	NC				NC	
DRDOL07T	16-May-91			NC	NC	NC				NC	
DRDOL07T	06-Jun-91			NC	NC	NC				NC	
DRDOL07T	08-Aug-91			NC	NC	NC				NC	
DRDOL07T	22-Apr-92	ND	*	NC						ND	
DRDOL07T	16-Jul-92			NC							
DRDOL08T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL08T	11-May-90	NC		NC	NC	*				NC	
DRDOL08T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL08T	11-Jul-90	*		*	NC	NC				NC	
DRDOL08T	07-Sep-90	NC		NC	NC	NC				NC	
DRDOL08T	14-May-91			NC	NC	NC				NC	
DRDOL08T	04-Jun-91			NC	NC	NC				NC	
DRDOL08T	13-Aug-91			NC	NC	NC				NC	
DRDOL08T	22-Apr-92			*							
DRDOL08T	15-Jul-92			*							
DRDOL09T	19-Sep-89	ND	ND	NC	ND	ND	ND	ND	ND	NC	ND
DRDOL09T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL09T	11-May-90	NC		*	ND		ND			NC	
DRDOL09T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL09T	11-Jul-90	NC		*	ND		ND			NC	
DRDOL09T	07-Sep-90	NC		NC	ND		ND			NC	
DRDOL09T	15-May-91			NC	ND		ND			NC	
DRDOL09T	04-Jun-91			NC	ND		ND			NC	
DRDOL09T	08-Aug-91			NC	ND		ND			NC	
DRDOL09T	21-Apr-92			NC	ND		ND		*		
DRDOL09T	15-Jul-92			NC	ND		ND				
DRDOL10T	17-Sep-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL10T	19-Sep-89	ND	ND	NC		NC		ND	ND	NC	ND
DRDOL10T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

DOLORES RIVER MERCURY STUDY - COMPARISON TO AQUATIC LIFE CRITERIA

		EXCEEDENCES OF CHRONIC WATER QUALITY STANDARDS									
STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL10T	10-May-90			*	NC	NC				NC	
DRDOL10T	29-May-90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL10T	29-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL10T	29-May-90			NC		ND			ND		ND
DRDOL10T	11-Jul-90			*	NC	NC				NC	
DRDOL10T	07-Sep-90			NC	NC	NC				NC	
DRDOL10T	14-May-91			NC	NC	NC				NC	
DRDOL10T	06-Jun-91			NC	NC	NC				NC	
DRDOL10T	08-Aug-91			NC	NC	NC				*	
DRDOL10T	23-Apr-92		*	*		*					
DRDOL10T	14-Jul-92		*	*		*					
DRDOL11T	19-Sep-89	NC	ND	NC		NC		ND	ND	NC	ND
DRDOL11T	17-Nov-89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL11T	10-May-90	NC		NC	NC	*				NC	
DRDOL11T	30-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL11T	11-Jul-90	NC		*	NC	NC				NC	
DRDOL11T	07-Sep-90	NC		NC	NC	NC				*	
DRDOL11T	14-May-91			NC	NC	NC				NC	
DRDOL11T	04-Jun-91			NC	NC	NC				NC	
DRDOL11T	16-Aug-91			NC	NC	NC				NC	
DRDOL11T	23-Apr-92			NC							
DRDOL11T	14-Jul-92			NC							
DRDOL12T	14-Nov-89	NC		*	NC					NC	
DRDOL12T	20-Dec-89	NC		*	NC				*	NC	
DRDOL12T	29-May-90	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND
DRDOL12T	29-May-90	NC	NC	NC	ND	ND			ND	ND	
DRDOL12T	13-Jun-90	*		NC	NC					NC	
DRDOL12T	11-Jul-90	NC		*	NC					NC	
DRDOL12T	29-Aug-90	*		*	*					NC	
DRDOL12T	14-May-91		*	NC	NC					NC	
DRDOL12T	04-Jun-91			NC	NC					NC	
DRDOL12T	05-Jun-91	NC		ND	NC					NC	
DRDOL12T	06-Aug-91			NC	NC					NC	
DRDOL12T	20-Apr-92			*							
DRDOL12T	15-Jul-92			*							
DRDOL13T	15-May-91			NC	NC	NC				NC	
DRDOL13T	10-Jun-91			NC	NC	NC				NC	
DRDOL13T	12-Aug-91			NC	NC	NC				NC	
DRDOL13T	22-Apr-92	ND	*	NC		*					
DRDOL13T	16-Jul-92		*	NC		*					
DRDOL14T	14-May-91			NC	NC	NC				NC	
DRDOL14T	10-Jun-91			*	NC	NC				NC	
DRDOL14T	08-Aug-91			NC	NC	NC				NC	
DRDOL14T	22-Apr-92	ND	*	NC		ND					
DRDOL14T	17-Jul-92		*	NC							
DRDOL15T	15-May-91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

DOLORES RIVER MERCURY STUDY - COMPARISON TO AQUATIC LIFE CRITERIA

STATION	DATE	EXCEEDENCES OF CHRONIC WATER QUALITY STANDARDS									
		Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL15T	10-Jun-91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL15T	20-Apr-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL15T	17-Jul-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL16T	15-May-91			NC	NC	NC				NC	
DRDOL16T	11-Jun-91			NC	NC	NC				NC	
DRDOL16T	22-Apr-92	ND	*	NC		*				ND	
DRDOL16T	14-Jul-92		*	NC		*					
DRDOL17T	15-May-91			NC	NC	NC				NC	
DRDOL17T	10-Jun-91			NC	NC	NC				NC	
DRDOL17T	13-Aug-91			NC	NC	NC				NC	
DRDOL17T	21-Apr-92		*	NC							
DRDOL17T	17-Jul-92		*	NC							
DRDOL18T	14-May-91			NC	NC	NC				NC	
DRDOL18T	10-Jun-91			*	NC	NC				NC	
DRDOL18T	13-Aug-91			NC	NC	NC				NC	
DRDOL18T	22-Apr-92		*	NC							
DRDOL18T	16-Jul-92			NC							
DRDOL19T	16-May-91			NC	NC	NC				NC	
DRDOL19T	10-Jun-91			NC	NC	NC				NC	
DRDOL19T	13-Aug-91			NC	NC	NC				NC	
DRDOL19T	22-Apr-92	ND	*	ND	ND	*		ND		ND	
DRDOL19T	16-Jul-92		*	NC		*					
DRDOL20T	16-May-91			NC	NC	NC				NC	
DRDOL20T	10-Jun-91			*	NC	NC				NC	
DRDOL20T	13-Aug-91			NC	NC	NC				NC	
DRDOL20T	21-Apr-92			NC		ND					
DRDOL20T	15-Jul-92			NC							
DRDOL21T	20-May-91			NC	NC	NC				NC	
DRDOL21T	11-Jun-91			NC	NC	NC				NC	
DRDOL21T	09-Aug-91			NC	NC	NC				NC	
DRDOL21T	24-Apr-92			*		*				ND	
DRDOL21T	13-Jul-92			NC		*					
DRDOL22T	20-May-91			NC	NC	NC			*	NC	
DRDOL22T	11-Jun-91			NC	NC	NC			*	NC	
DRDOL22T	06-Aug-91	*		NC	NC	NC		*	*	NC	
DRDOL22T	13-Jul-92			*						*	
DRDOL23T	20-May-91			NC	NC	NC				NC	
DRDOL23T	11-Jun-91			NC	NC	NC				NC	
DRDOL23T	09-Aug-91			NC	NC	NC				NC	
DRDOL23T	24-Apr-92			*		*					
DRDOL23T	13-Jul-92			NC							
DRDOL24T	24-May-91	NC		ND	ND	NC	ND			NC	
DRDOL24T	04-Jun-91			NC	ND	NC	ND			NC	
DRDOL24T	08-Aug-91			NC	ND	NC	ND			NC	
DRDOL24T	21-Apr-92	ND	ND	ND	ND	ND	ND	ND		ND	ND
DRDOL24T	14-Jul-92		*	NC	ND		ND		*		

DOLORES RIVER MERCURY STUDY - COMPARISON TO AQUATIC LIFE CRITERIA

		EXCEEDENCES OF CHRONIC WATER QUALITY STANDARDS									
STATION	DATE	Cd	Cu	Hg	Se	Ag	As	Zn	Mn	Pb	Ni
DRDOL25T	22-May-91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL25T	10-Jun-91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL25T	20-Apr-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL25T	17-Jul-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL26T	09-Aug-91			NC	NC	NC				NC	
DRDOL26T	24-Apr-92		*	NC	ND					ND	
DRDOL26T	13-Jul-92			NC							
DRDOL27T	09-Aug-91			NC	NC	NC				NC	
DRDOL28T	12-Aug-91	*		NC	NC	NC		*	*	NC	
DRDOL28T	14-Jul-92		*	*	*	*	*	*	*	*	
DRDOL29T	16-Aug-91	*	*	NC	NC	NC		*	*	*	
DRDOL29T	14-Jul-92		*	*	*	*	*	*	*	*	
DRDOL30T	20-Apr-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL30T	17-Jul-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DRDOL31T	23-Apr-92		*	NC	ND	*	ND				
DRDOL31T	15-Jul-92			NC	ND	*	ND				
DRDOL32T	23-Apr-92			NC		ND			*		
DRDOL32T	16-Jul-92			NC							
DRDOL33T	23-Apr-92			ND	ND	ND				ND	
DRDOL34T	23-Apr-92	ND		NC		ND				ND	
DRDOL34T	16-Jul-92		*	NC							
DRDOL35T	24-Apr-92			NC						ND	
DRDOL36T	24-Apr-92	ND	ND	NC	ND	ND	ND	ND		ND	
DRDOL36T	16-Jul-92		*	NC							
DRDOL37T	24-Apr-92	ND		NC		ND		ND		ND	
DRDOL37T	16-Jul-92		*	NC							
DRDOL38T	24-Apr-92		ND	*		ND					
DRDOL38T	16-Jul-92			*							
DRDOL39T	24-Apr-92			*		*					
DRDOL40T	13-Jul-92			NC							
DRDOL41T	13-Jul-92			NC							
DRDOL42T	14-Jul-92			NC							
DRDOL43T	14-Jul-92			NC							
DRDOL44T	16-Jul-92		*	*							
DRDOL45T	17-Jul-92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

* EXCEEDS STANDARD
ND MISSING DATA OR NO CRITERION
NC DETECTION LIMIT > CRITERION

APPENDIX D

Minerals Reported from the Rico Mining District

Common Ore-forming Minerals in the Rico Mining District (McKnight, 1974)	
Mineral (Rico Report)	Composition (Minerals Ref)
Native Gold	Au (McKnight, 1974)
Hematite	α-Fe_2O_3 (Deer *et al.*, 1992)
Magnetite	Fe_3O_4 (Deer *et al.*, 1992)
Pyrite	FeS (McKnight, 1974) Abundant.
Pyrrhotite	Fe_7S_8-FeS (Deer *et al.*, 1992)
Sphalerite	ZnS (McKnight, 1974) Next in abundance to pyrite. Fairbridge (1972) indicates it may contain Hg.
Galena	PbS (McKnight, 1974)
Chalcopyrite	(Cu,Fe)S (McKnight, 1974) copper ore in Rico.
Tetrahedrite - Tennantite	$Cu_3(Sb,As)^{III}S_3$ (Fairbridge, 1972)- Both may contain traces of Hg and are then called schwazite and hermesite respectively, neither of which is mentioned by McKnight (1974).
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$ McKnight (1974) indicates it is part of the primary Ag ore in the District.
Pyrargyrite (ruby silver)	Ag_3SbS_3 - McKnight (1974) indicates it is part of the primary Ag ore in the District.
Argyrodite	$GeS_2 \cdot 4Ag_2S$ (Fairbridge, 1972) indicates it may contain Hg.
Argentite, Proustite, Pearcite, & Stephanite-?	Ag_2S, Ag_3AsS_3, $8(Ag,Cu)_2S \cdot As_2S_3$, Ag_5SbS_4 - Fairbridge (1972); they were once significant ores of silver in the District, according to McKnight (1974).
Cosalite	$Pb_2Bi_2S_5$ (McKnight, 1974)
Tetradymite	Bi_2Te_2S (McKnight, 1974)
Alabandite	MnS (McKnight, 1974)

Gangue Minerals in the Rico Mining District	
Mineral (Rico Report)	Composition (Minerals Ref)
Quartz	SiO_2 (McKnight, 1974)
Jasperoid	Silicified $CaCO_3$ (McKnight, 1974)
Calcite	$CaCO_3$ (McKnight, 1974)
Dolomite	$(Ca,Mg)CO_3$ (McKnight, 1974)
Rhodochrosite	$MnCO_3$ (Deer *et al.*, 1992)
Rhodonite	$(Mn,Ca,Fe)[SiO_3]$ (Deer *et al.*, 1992)
Sellaite	MgF_2 (McKnight, 1974)
Sericite (Phlogopite & Muscovite)	A fine-grained white mica that may be either phlogopite $\{K_2Mg_6[Si_6Al_2O_{20}](OH)_4\}$ or muscovite $\{K_2Al_4[Si_6Al_2O_{20}](OH,F)_4\}$ (Deer *et al.*, 1992).
Apatite	$Ca(PO_4)F$ (Deer *et al.*, 1992)
Huebnerite	$MnWO_4$ (McKnight, 1974)
Adularia	A potasium feldspar ($K[AlSi_3O_8]$) - McKnight (1974)
Kaolinite	A clay mineral (alumino-silicate)
Barite	$BaSO_4$ (McKnight, 1974)
Aragonite	$CaCO_3$ (Deer *et al.*, 1992)
Helvite	$(Mn,Fe,Zn)_8Be_6Si_6O_{24}S_2$ (Deer *et al.*, 1992)

Metamorphic Minerals occasionally Associated with Ores	
Mineral (Rico Report)	Composition (Minerals Ref)
Garnet Group	Ranges from andradite [$Ca_3(Fe^{+3},Ti)_2Si_3O_{12}$] to grossularite [$Ca_3Al_2Si_3O_{12}$] (McKnight, 1974)
Diopside-Hedenbergite	$Ca(Mg,Fe)[Si_2O_6]$ (Deer *et al.*, 1992)
Epidote	$Ca_2Al_2O.(Al,Fe^{+3})OH[Si_2O_7][SiO_4]$ (Deer *et al.*, 1992)
Clinozoisite	$Ca_2Al_2O.AlOH[Si_2O_7][SiO_4]$ (Deer *et al.*, 1992)
Chlorite	$(Mg,Fe^{+2},Fe^{+3},Mn,Al)_{12}[(Si,Al)_8O_{20}](OH)_{16}$ (Deer *et al.*, 1992)
Tremolite	$Ca_2(Mg,Fe^{+2})_5[Si_8O_{22}](OH,F)_2$ (Deer *et al.*, 1992)
Actinolite	$Ca_2(Mg,Fe^{+2})_5[Si_8O_{22}](OH,F)_2$ (Deer *et al.*, 1992)
Hornblende	$Ca_2(Mg,Fe)_4Al[Si_7AlO_{22}](OH)_2$ (Deer *et al.*, 1992)
Albite	$Na(Si_3Al)O_8$ (Deer *et al.*, 1992) - sodium feldspar.
Potassium Feldspar	$K(Si_3Al)O_8$ (Deer *et al.*, 1992)
Allanite	$(Ca,Mn,Ce,La,Y,Th)_2(Fe^{+2},Fe^3,Ti)(Al,Fe^{+3})_2O.OH-[Si_2O_7][SiO_4]$ (Deer *et al.*, 1992)
Biotite	$\{K_2Mg_6[Si_6Al_2O_{20}](OH)_4\}$ (Deer *et al.*, 1992)
Serpentine	$Mg_3[Si_2O_5](OH)_4$ (Deer *et al.*, 1992)
Topaz	$Al_2[SiO_4](OH,F)_2$ (Deer *et al.*, 1992)
Diaspore	α-AlO(OH) (Deer *et al.*, 1992)
Andalusite	Al_2SiO_5 (Deer *et al.*, 1992)
Cordierite	$(Mg,Fe)_2[Si_5Al_4O_{18}]\cdot nH_2O$ (Deer *et al.*, 1992)
Tourmaline	$(Na,Ca)(Mg,Fe,Mn,Li,Al)_3(Al,Mg,Fe^{+3})_6[Si_6O_{18}](BO_3)_3(O,OH)_3(O,OH)$ (Deer *et al.*, 1992)
Prehnite	$Ca_2(Al,Fe^{+3})[AlSi_3O_{10}](OH)_2$ (Deer *et al.*, 1992)
Rutile	TiO_2 (Deer *et al.*, 1992)
Sphene	$CaTi[SiO_4](O,OH,F)$ (Deer *et al.*, 1992)

Supergene Minerals in the Rico Mining District	
Mineral (Rico Report)	Composition (Minerals Ref)
Limonite	$FeOOH \cdot nH_2O$ (Deer *et al.*, 1992)
Anglesite	$PbSO_4$ (Fairbridge, 1972)
Cerussite	$PbCO_3$ (Deer *et al.*, 1992)
Smithsonite	$ZnCO_3$ (Deer *et al.*, 1992)
Malachite	$Cu_2(OH)_2CO_3$ (Deer *et al.*, 1992)
Serpierite	$(Zn,Cu,Ca)_5(SO_4)_2(OH)_6 \cdot 3H_2O$ (?) Fairbridge (1972)
Gypsum	$CaSO_4$ McKnight (1974)
Pyrolusite	MnO_2 McKnight (1974)

References:

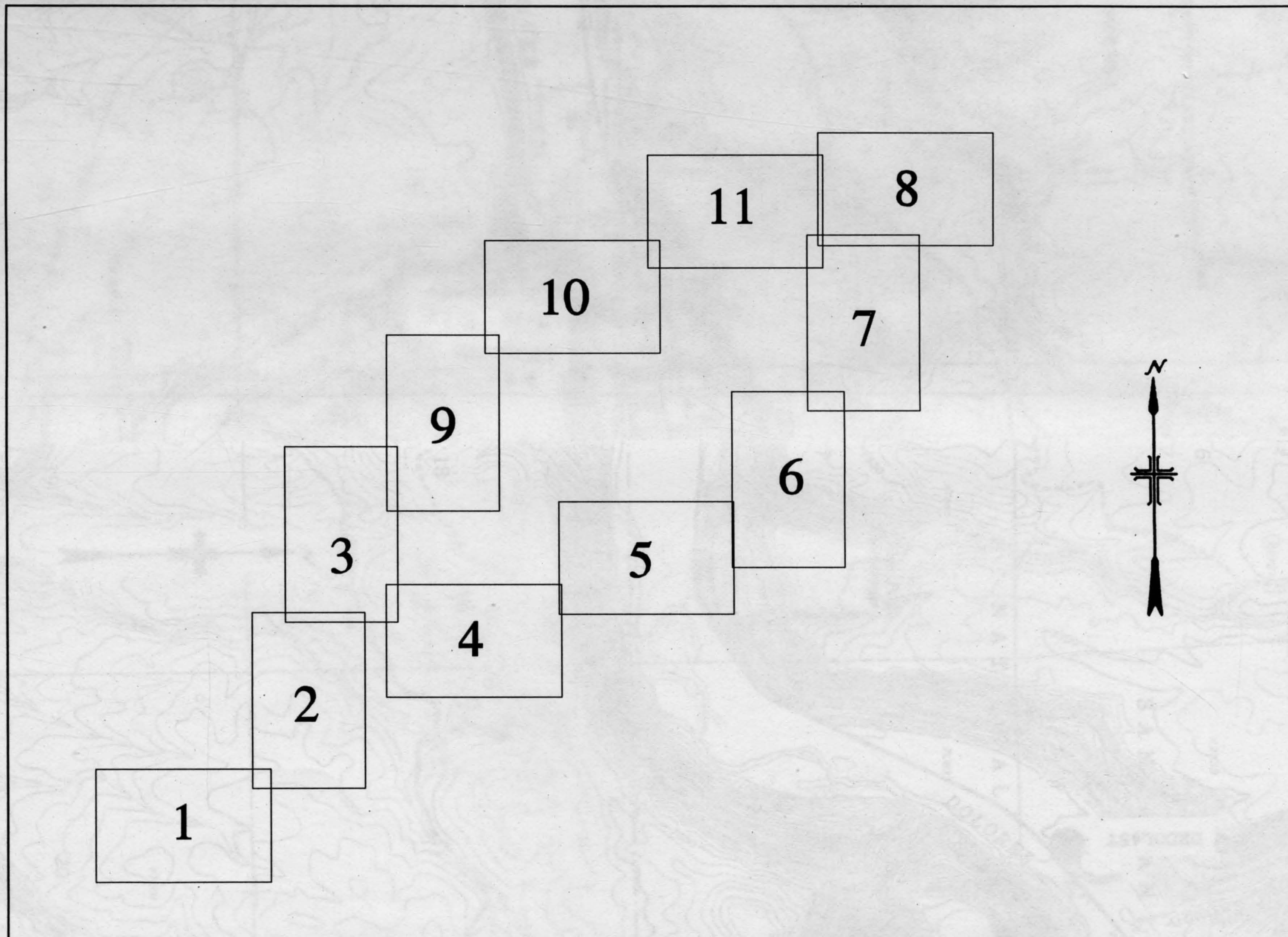
Deer, W.A., R.A. Howie, and J. Zussman, 1992. An Introduction to the Rock-Forming Minerals, 2nd ed., Longman Scientific & Technical, London, U.K., 696 pp. + 1 plate.

Fairbridge, Rhodes W., 1972. The Encyclopedia of Geochemistry and Environmental Sciences, Encyclopedia of Earth Sciences Series, vol. IVA. Dowden, Hutchinson, & Ross, Inc., Stroudsburg, PA, 1321 pp.

McKnight, Edwin T., 1974. Geology and Ore Deposits of the Rico District, Colorado. Geological Survey Professional Paper 723, U.S. Government Printing Office, Washington, DC, 100 pp. + 3 plates.

APPENDIX E

Location Map Index and Location Maps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1
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6
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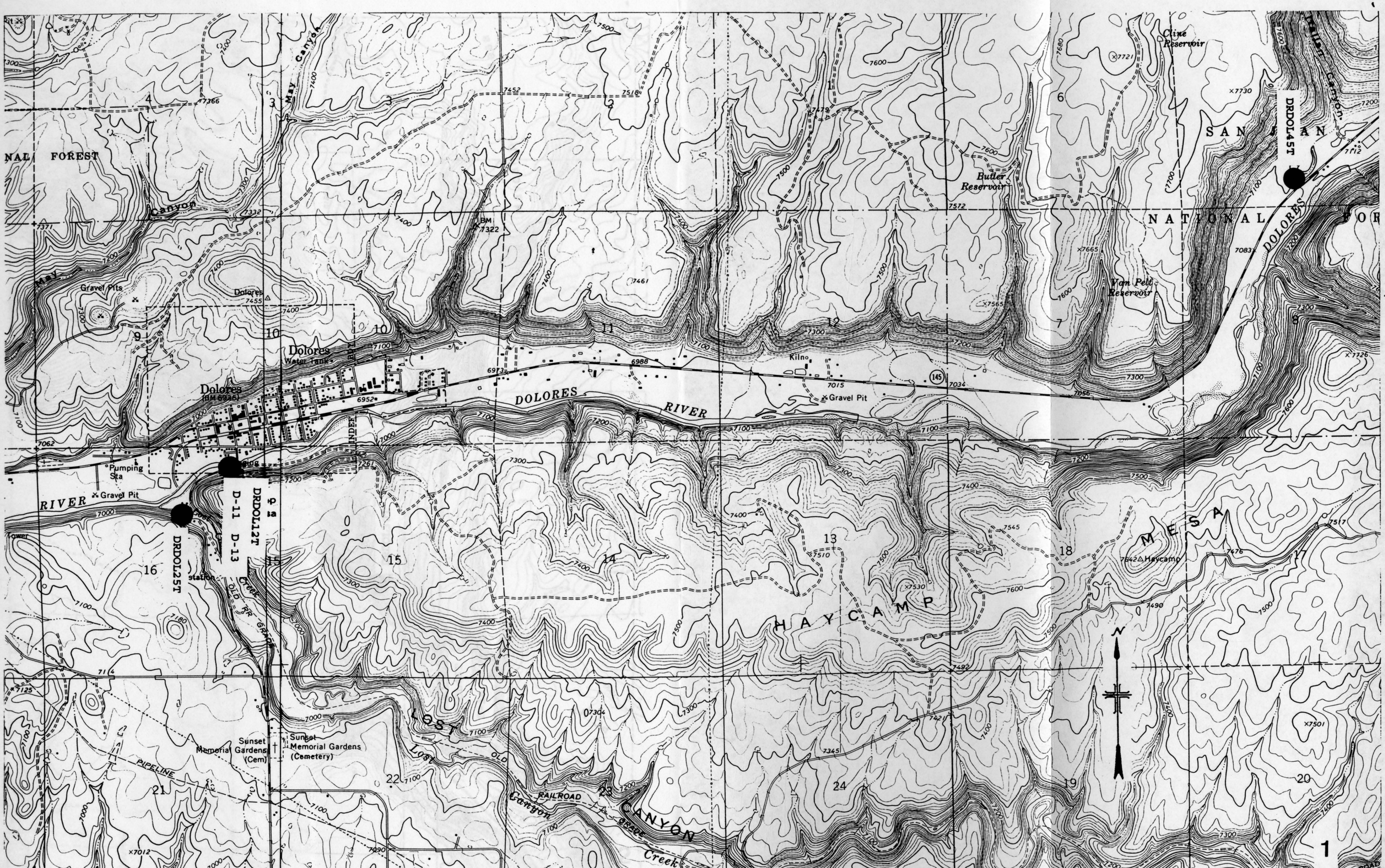
8
9
10
11

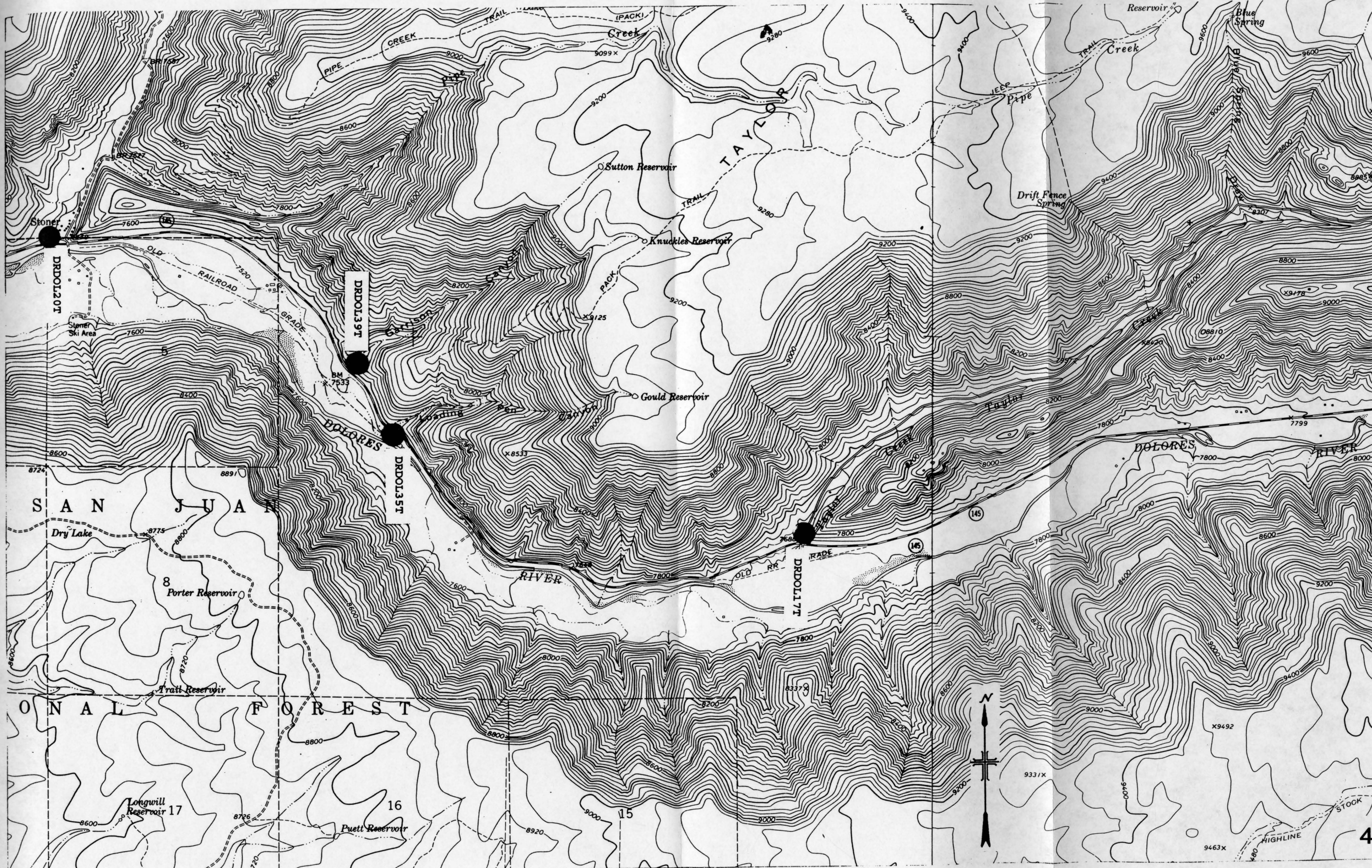


DRDOL45T
DRDOL12T
D-11
D-13
DRDOL25T
Dolores
Dolores (BM 6936)
DOLORES RIVER
RIVER
HAYCAMP MESA
LOST CANYON
Lost Canyon Creek
May Canyon
NATIONAL FOREST
SAN JUAN NATIONAL FOREST
Gravel Pits
Gravel Pit
Water Tank
Pumping Sta
Kilns
Butler Reservoir
Cline Reservoir
Van Pelt Reservoir
Sunset Memorial Gardens (Cemetery)
Sunset Memorial Gardens (Cem)
PIPELINE
OLD RAILROAD GRADE
Haycamp
145

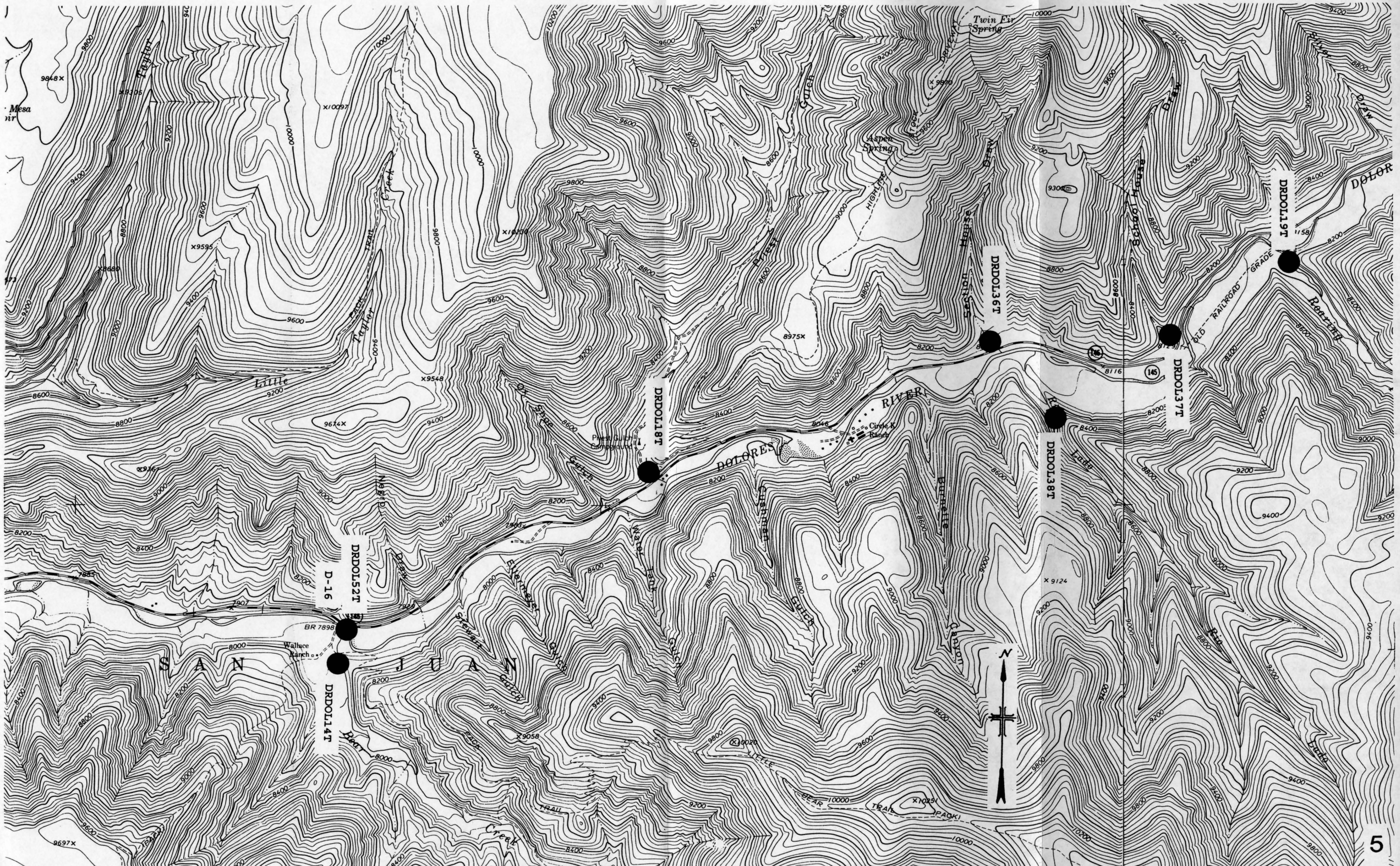
1


Reservoir
9
10
8075
8100
8200
8263
8300
Canyon
OLD RAILROAD
Longwill Spring
8463
8400
7600
7400
8000
7500
145
Akin Reservoir
8553
16
15
8122
BM
7270
7269
Cox Reservoir
7800
8350
8280
8026
8000
8100
Thomas Reservoir
8200
21
7973
22
8254
7241
Tucker Reservoir
Water
8205
7992
7217
RIVER
Haycamp Point Reservoir
Spruce
Smoothing Reservoir
7970
28
27
7900
7700
7300
DRDOL15T
Spruce Water Canyon
DOLORES
8160
East Italian Reservoir
7922
Wilkerson Spring
Wallace Reservoir
33
34
8186
7871
DRDOL30T
8120
7148
4
3
7134
DRDOL46T
D-14
Mesa
RIVER
Haycamp
3
3
2
1
Fish Hatchery
7822
POINT
7200
2

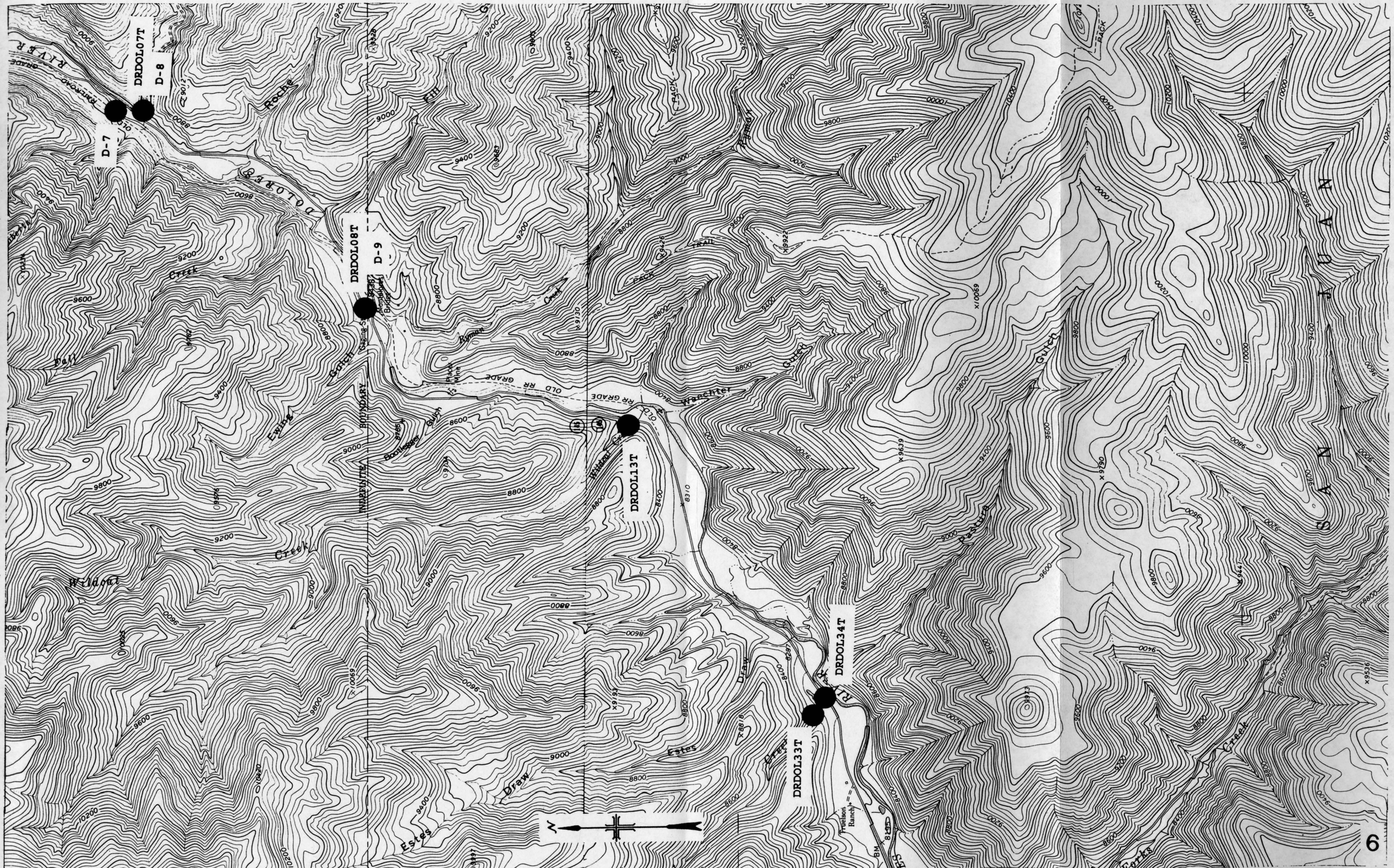

Draw
Bald Hill Reservoir
Bald Hill
Coffee Camp Reservoir
Mc Cabe Reservoir
Drift Fence Reservoir
STONER
STOCK
TRAIL
JEEP
Rocky
Draw
Rocky Draw
Emerson Campground
DOLORES CO
MONTEZUMA CO
DOLORES CO
MONTEZUMA CO
Eldon Reservoir
Oak Knolls Reservoir
RIVER
WEST
DOLORES
Vick Spring
PACK
TRAIL
Stoner Point Reservoir
Stoner Point Reservoir No 3
Spring
Creek
TRAIL
Boggy Draw Reservoir
Cox Canyon
DRDOL24T
D-15
The Forks Campground
DRDOL09T
D-10
RIVER
Stoner Guard Station
BR 7386
DOLORES
GRADE
BM 7331
Steep Spring
T 39 N
T 38 N
10
10
11
12
15
15
14
13
22
22
27
34
3
6



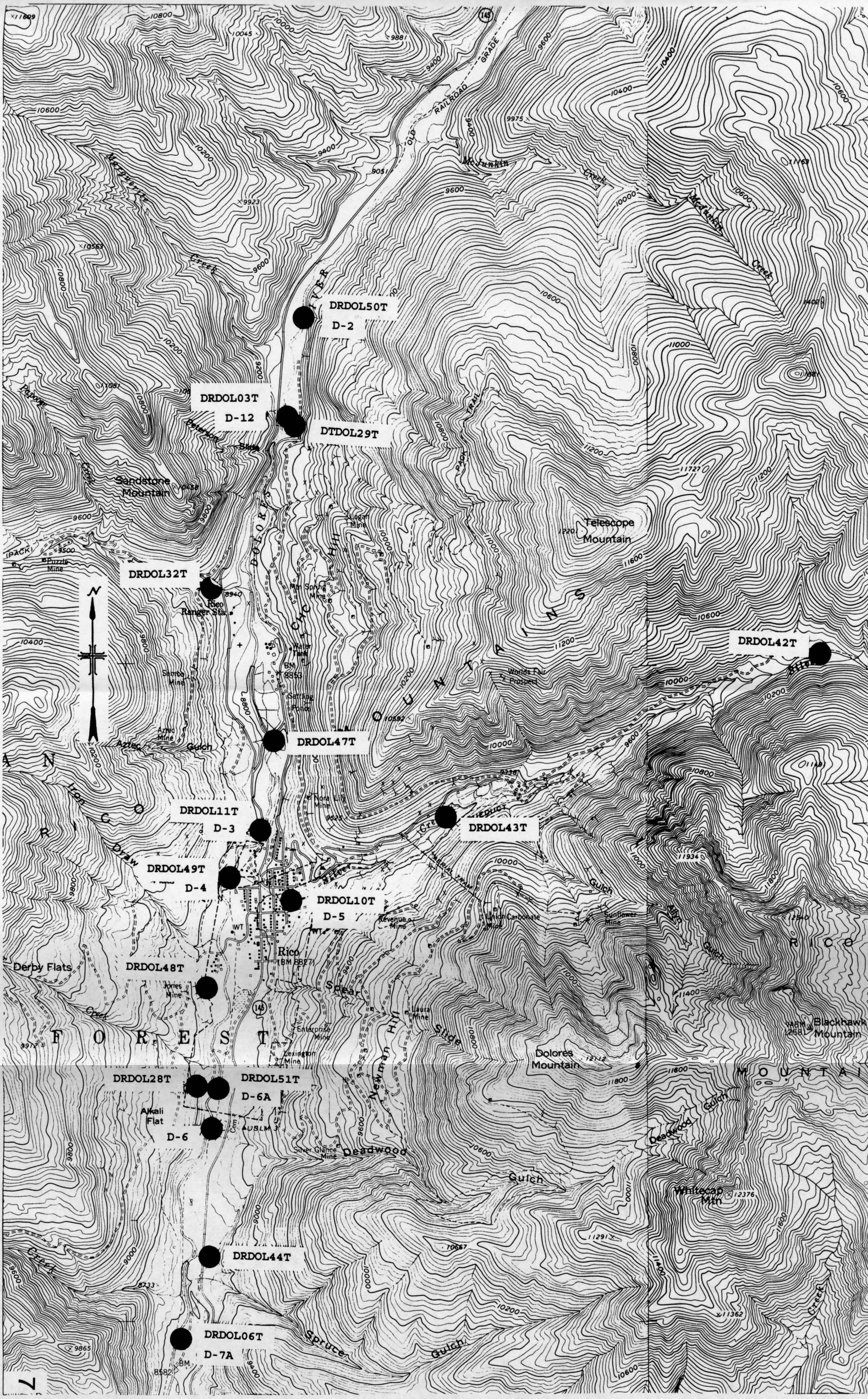
Stoner
DRDOL20T
DRDOL39T
DRDOL35T
DRDOL17T
Stoner Ski Area
Sutton Reservoir
Knuckles Reservoir
Gould Reservoir
Drift Fence Spring
Blue Spring
Reservoir
Dry Lake
Porter Reservoir
Trail Reservoir
Longwill Reservoir
Puett Reservoir
SAN JUAN
ONAL FOREST
DOLORES
RIVER
Garrison
Canyon
Loading Pen Canyon
Taylor
Creek
Pipe
TAYLOR
TRAIL
OLD RAILROAD GRADE
PIPE CREEK TRAIL
JEEP
PACK
HIGHLINE
STOCK
145
BM 7533
N

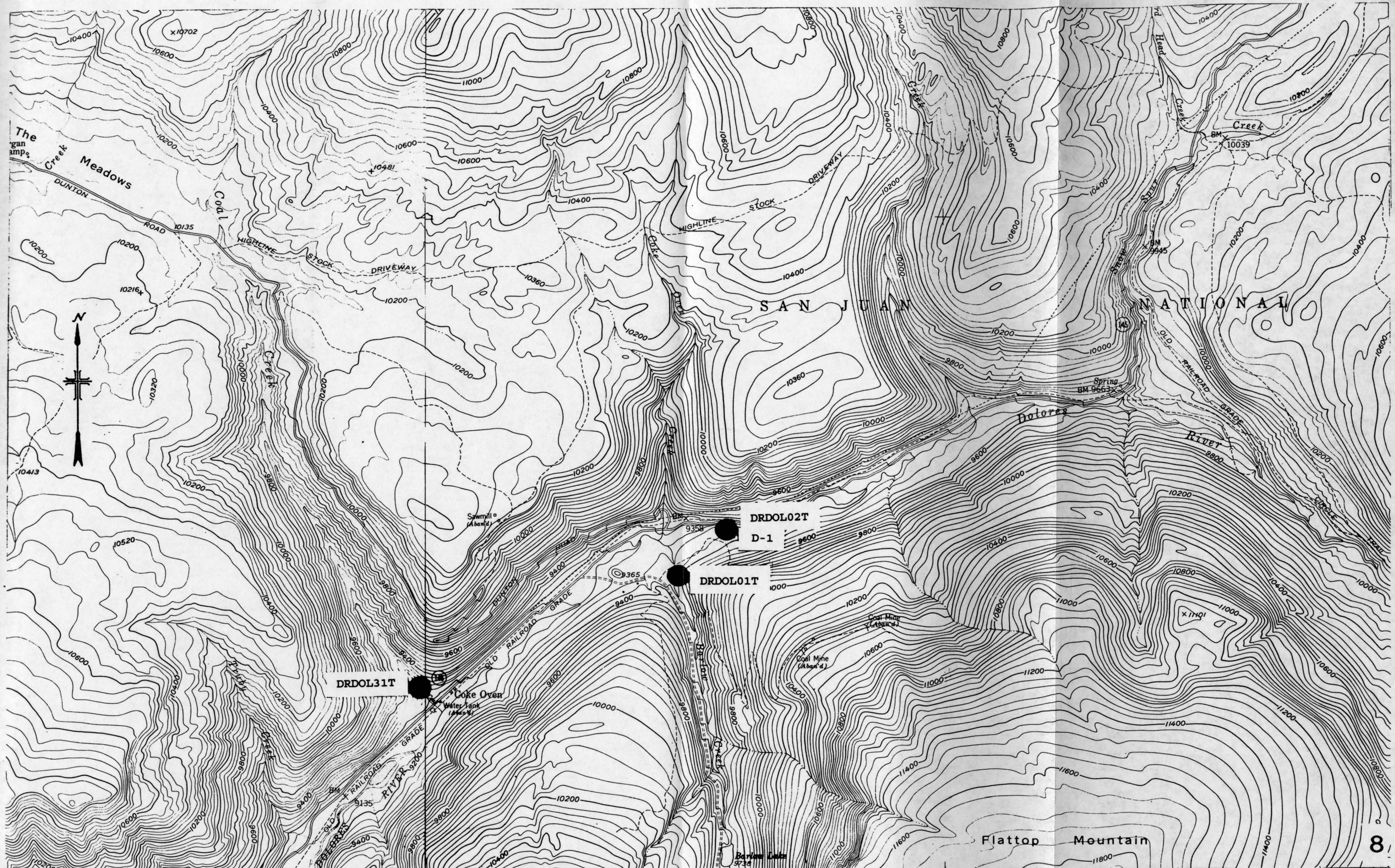


DRDOL19T
DRDOL36T
DRDOL37T
DRDOL38T
DRDOL18T
DRDOL52T
D-16
DRDOL14T
DOLORES
RIVER
SAN JUAN
Twin Fir Spring
Aspen Spring
Priest Gulch Campground
Circle K Ranch
Wallace Ranch
OLD RAILROAD GRADE
Priest Gulch
Ox Shoe Gulch
Section House Draw
School House Draw
Cushman Gulch
Burnette Canyon
Water Tank Gulch
Stewart Gulch
Taylor Creek
Little
Roaring
Bear Creek
N

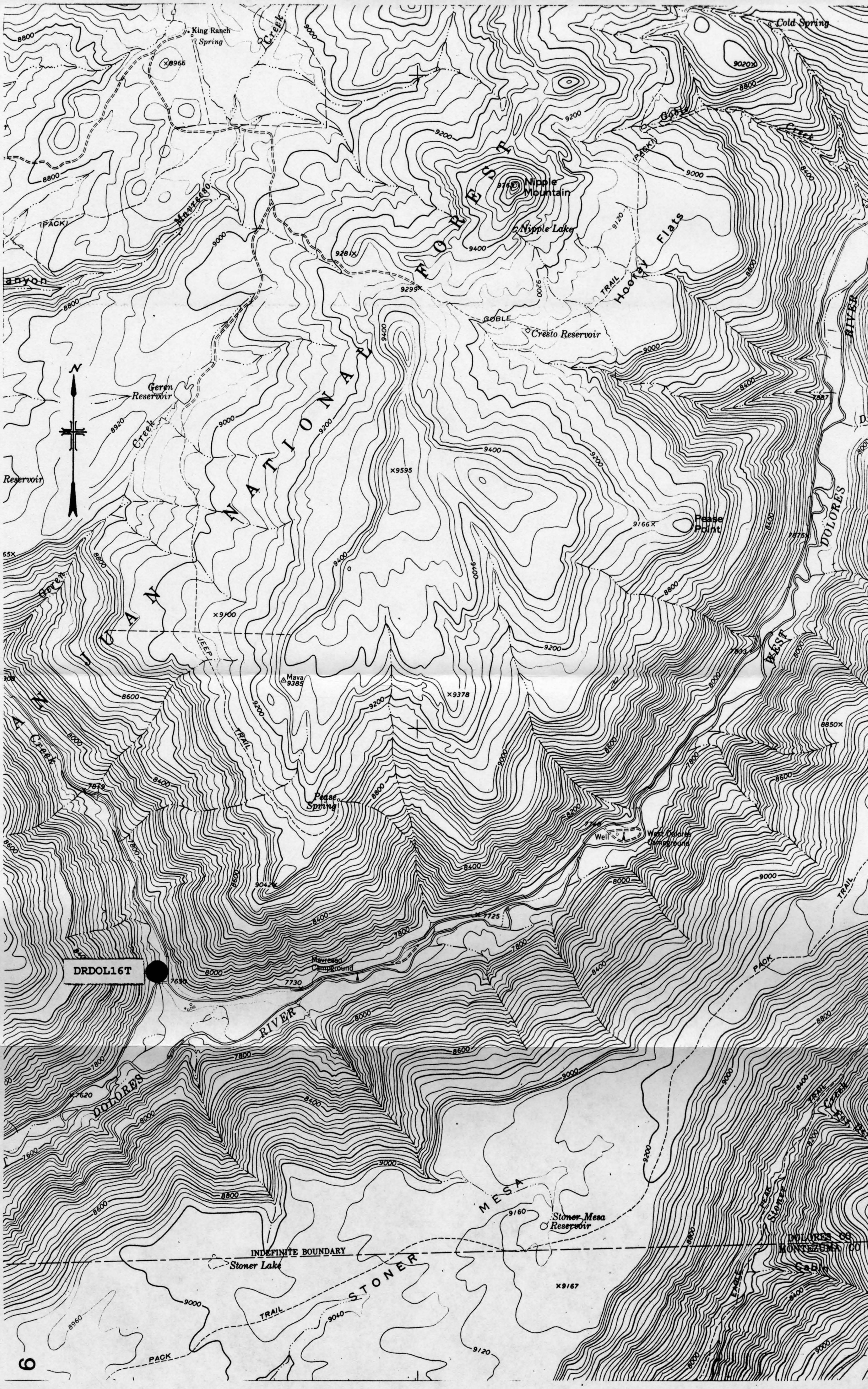


DRDOL07T
D-8
D-7
DRDOL08T
D-9
DRDOL13T
DRDOL34T
DRDOL33T
DOLORES
RIVER
Roche
Creek
Ewing
Gulch
Wildcat
Creek
Estes
Draw
Ryman
Creek
Bootlegger
Gulch
Waechter
Gulch
Pasture
Gulch
OLD RR GRADE
INDEFINITE BOUNDARY
PACK TRAIL
Truelson Ranch
Forks
Creek
S A N J U A N

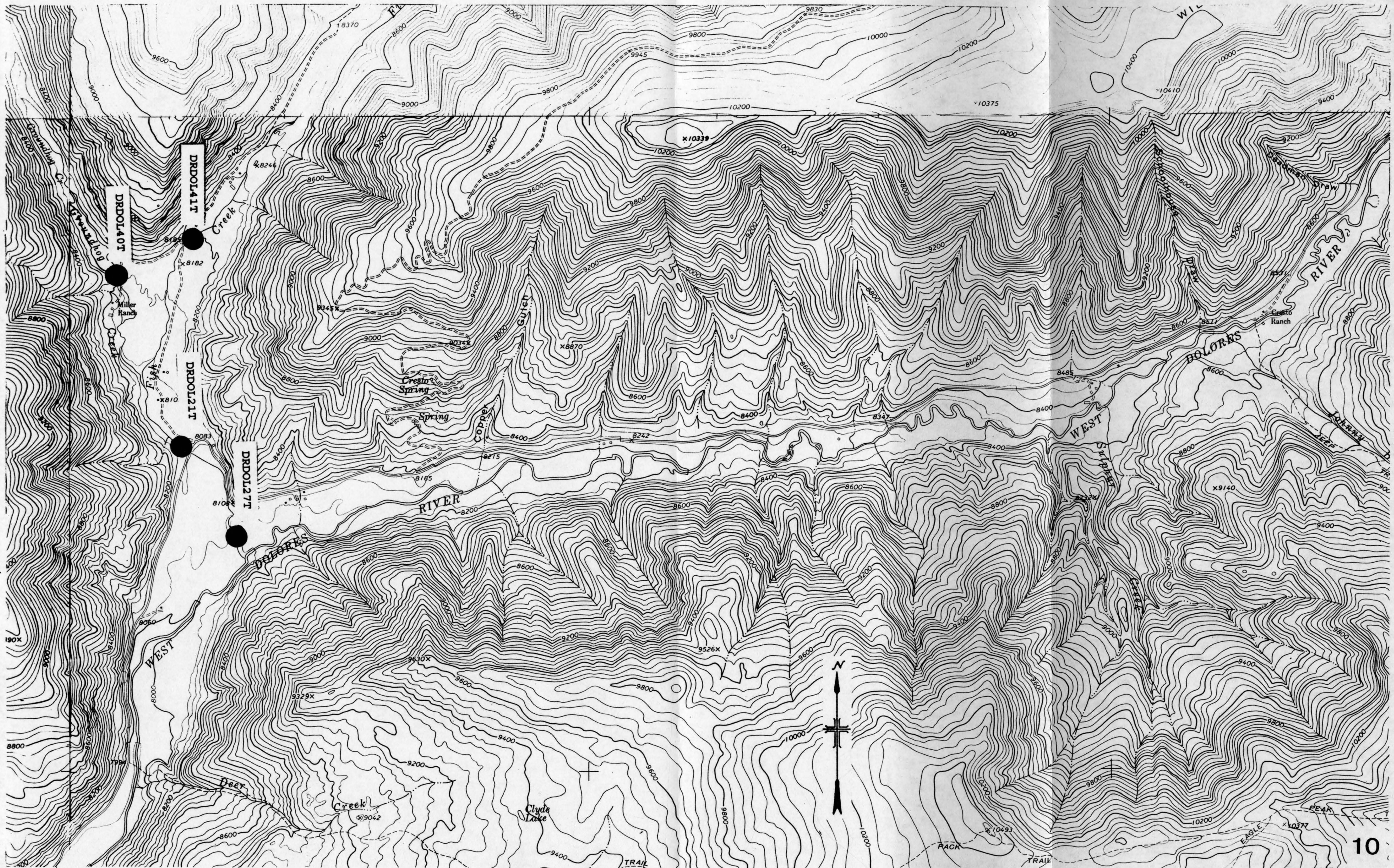

DRDOL50T
D-2
DRDOL03T
D-12
DTDOL29T
DRDOL32T
DRDOL42T
DRDOL47T
DRDOL11T
D-3
DRDOL43T
DRDOL49T
D-4
DRDOL10T
D-5
DRDOL48T
DRDOL28T
DRDOL51T
D-6A
D-6
DRDOL44T
DRDOL06T
D-7A
Sandstone Mountain
Telescope Mountain
Rico Ranger Sta.
Rico
Derby Flats
Alkali Flat
Dolores Mountain
Blackhawk Mountain
Whitecap Mtn
Aztec Gulch
Deadwood Gulch
Spruce Gulch
Newman Hill
Spear
Slide
OLD RAILROAD GRADE
McJunkin Creek
Silver Creek
FOREST
RICO
MOUNTAI



DRDOL02T
D-1
DRDOL01T
DRDOL31T
SAN JUAN
NATIONAL
Dolores
River
Coke Oven
Water Tank
Sawmill (Aban'd)
Coal Mine (Aban'd)
Spring
BM 9663
BM 9945
BM 10039
BM 9135
9358
9365
HIGHLINE STOCK DRIVEWAY
DUNTON ROAD
OLD RAILROAD GRADE
DOLORES RIVER
Coal Creek
Coke Oven Creek
Barlow Creek
Snow Spur Creek
Meadows
Flattop Mountain
Barlow Lake
9736
145
N



King Ranch Spring
Cold Spring
Creek
Nipple Mountain
Nipple Lake
Goble Creek
Hooray Flats
TRAIL
GOBLE
Cresto Reservoir
(PACK)
Mavreeso
Canyon
SAN JUAN NATIONAL FOREST
Geren Reservoir
Creek
Reservoir
Geren
N
Pease Point
WEST DOLORES RIVER
Mava 9385
JEEP
TRAIL
Pease Spring
Well
West Dolores Campground
Creek
DRDOL16T
Mavreeso Campground
RIVER
DOLORES
PACK
TRAIL
MESA
Stoner Mesa Reservoir
INDEFINITE BOUNDARY
Stoner Lake
STONER
TRAIL
PACK
DOLORES CO
MONTEZUMA CO
Cabin
EAGLE
PEAK
Stoner
Creek



DRDOL41T
DRDOL40T
DRDOL21T
DRDOL27T
Groundhog Cr.
Miller Ranch
Fish Creek
Cresto Spring
Spring
Copper Gulch
DOLORES RIVER
WEST DOLORES RIVER
Cresto Ranch
Schoolhouse Draw
Deadman Draw
Johnny
JEEP
West Sulphur Creek
West Deer Creek
Clyde Lake
PACK TRAIL
EAGLE PEAK
TRAIL
N

N A T I O N A L F O R E S T
BURRO BRIDGE 9135
Burro Bridge Campground
DUNTON ROAD
West Dolores River
Dunton Guard Sta
DRDOL23T
DRDOL05T
Dunton (Rancho Dolores)
Dunton Hot Spring
Falls
Emma Mine 8811
Mine
Eagle Falls
Smuggler Mine
Mines
9508
Fall Creek
Eagle Creek
Geyser Creek
Morrison Creek
Meadow
Creek
WINTER TRAIL
HIGHLINE STOCK DRIVEWAY
DRDOL22T
DRDOL26T
DRDOL04T
West Dolores River
8605
Geyser Park
East Fork
West
Papoose Peak
VABM 11866
TRACK
PACK TRAIL
10653
10886
11228
10662
9971
N